

**TWENTY-FIRST ANNUAL REPORT**  
**OF THE**  
**NATIONAL ADVISORY COMMITTEE**  
**FOR AERONAUTICS**

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**1935**

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**INCLUDING TECHNICAL REPORTS**

**Nos. 508 to 541**



**UNITED STATES**  
**GOVERNMENT PRINTING OFFICE**  
**WASHINGTON : 1936**



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## LETTER OF SUBMITTAL

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TO THE CONGRESS OF THE UNITED STATES:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the Twenty-first Annual Report of the Committee, covering the fiscal year ended June 30, 1935.

FRANKLIN D. ROOSEVELT.

THE WHITE HOUSE,  
*January 7, 1936.*



## LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,  
*Washington, D. C., December 10, 1935.*

MR. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to transmit herewith the Twenty-first Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1935.

The United States has continued to lead the world in the development of aircraft of superior performance, efficiency, range, and safety.

As attainable speeds increase, fundamental problems requiring scientific research and technical investigation multiply. The ability of this Committee to anticipate and to meet the research needs of aviation in the United States is an important factor in the remarkable development of aircraft to date.

The recent successful inauguration of trans-Pacific air service to China is a forerunner of a new era in which strenuous efforts will be made by far-sighted nations to establish and, if possible, to control trade routes of the air. In these efforts an important, if not decisive, advantage will lie with the nation that has superior aircraft, which means the nation that has the greatest initiative and vision in providing new and improved research facilities and in supporting long-range programs of organized fundamental scientific research.

The research laboratories of this Committee at Langley Field, Va., are at the present time unsurpassed, but other nations have plans under way for providing more modern and more efficient research facilities. This Committee is hopeful that, with the continued support of the Congress, it will be able to retain the present advantage of the United States in this field.

Attention is invited to the opening portion of the report in which the Committee presents its views as to the significance of world developments and as to the trend of development in aeronautics.

Respectfully submitted.

JOSEPH S. AMES, *Chairman.*

THE PRESIDENT,  
*The White House, Washington, D. C.*





# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

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Director of Air Commerce, Department of Commerce.

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New York City.

R. D. WEYERBACHER, Commander, United States Navy,  
Bureau of Aeronautics, Navy Department.

ORVILLE WRIGHT, Sc. D.,  
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JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer in Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

JOHN J. IDE, *Technical Assistant in Europe, Paris, France*

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## TECHNICAL COMMITTEES

AERODYNAMICS  
POWER PLANTS FOR AIRCRAFT  
AIRCRAFT STRUCTURES AND MATERIALS

AIRCRAFT ACCIDENTS  
INVENTIONS AND DESIGNS

*Coordination of Research Needs of Military and Civil Aviation*

*Preparation of Research Programs*

*Allocation of Problems*

*Prevention of Duplication*

*Consideration of Inventions*

## LANGLEY MEMORIAL AERONAUTICAL LABORATORY

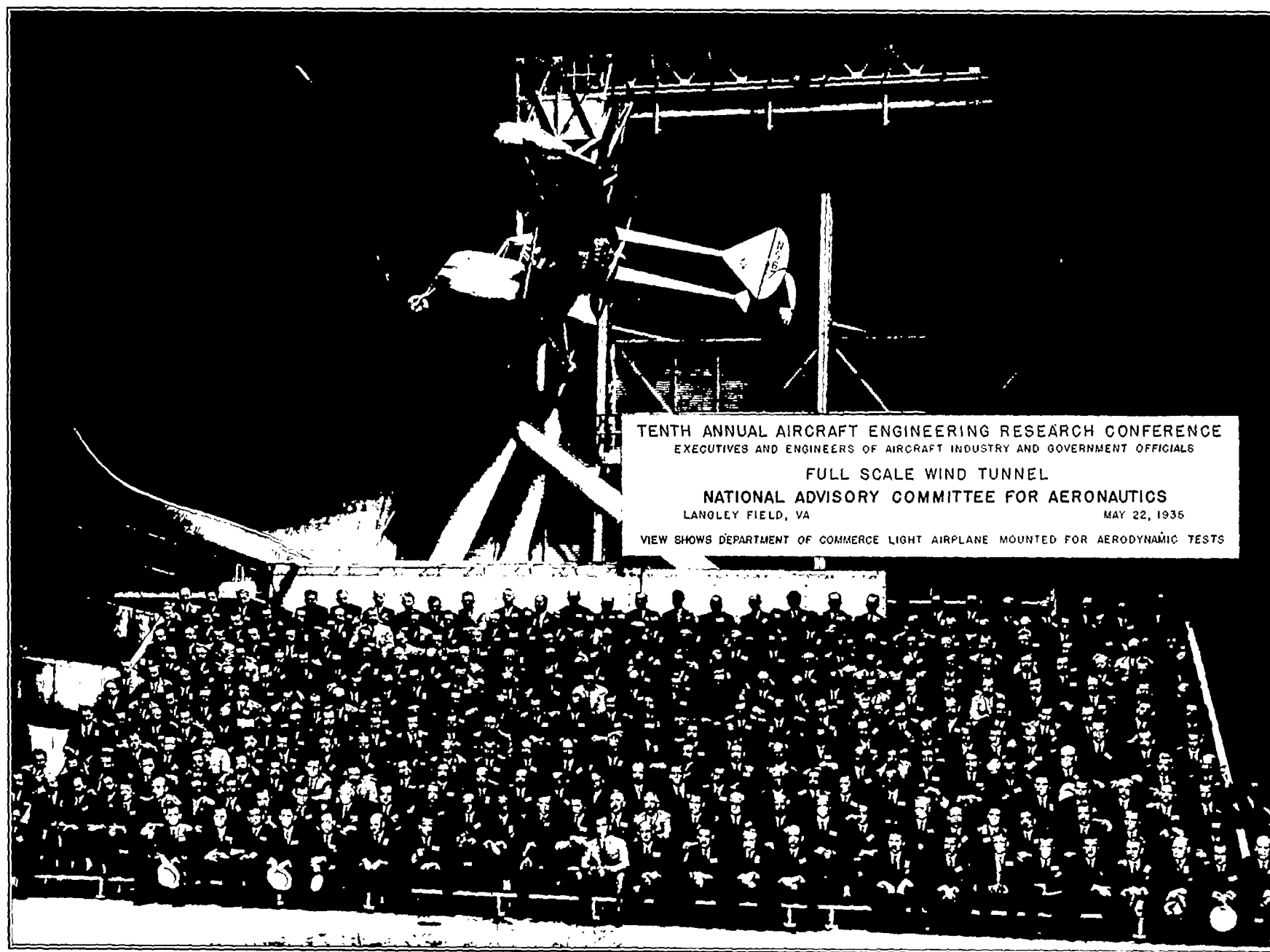
LANGLEY FIELD, VA.

Unified conduct, for all agencies, of  
scientific research on the fundamental  
problems of flight.

## OFFICE OF AERONAUTICAL INTELLIGENCE

WASHINGTON, D. C.

Collection, classification, compilation,  
and dissemination of scientific and tech-  
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EXECUTIVES AND ENGINEERS OF AIRCRAFT INDUSTRY AND GOVERNMENT OFFICIALS

FULL SCALE WIND TUNNEL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

LANGLEY FIELD, VA

MAY 22, 1935

VIEW SHOWS DEPARTMENT OF COMMERCE LIGHT AIRPLANE MOUNTED FOR AERODYNAMIC TESTS

# TWENTY-FIRST ANNUAL REPORT

## OF THE

# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C. November 12, 1935.

*To the Congress of the United States:*

In accordance with the act of Congress approved March 3, 1915, which established the National Advisory Committee for Aeronautics, the Committee submits herewith its twenty-first annual report, covering the fiscal year 1935.

**Significance of World Developments.**—The past year has seen gratifying progress in American aeronautical development. There has also been abundant evidence of increased interest on the part of progressive nations throughout the world in the development of military and civil aircraft. This is largely due to general recognition of the increasing utility and dependability of aircraft. In the United States there has been substantial improvement in the performance, range, efficiency, and safety of aircraft. This is the normal result of continuous research and development in many fields. The value of research is being more widely appreciated, and at the present time there is intensive activity in foreign nations in providing and enlarging their research facilities in aeronautics and in planning long-range programs in the field of aeronautical research and development.

During the past year there has been much interest in foreign nations in American achievements in aeronautics and in the factors that have made for progress in the United States. Numerous aeronautical missions and technical representatives have been sent to this country, and almost without exception they have requested permission to visit the laboratories of the National Advisory Committee for Aeronautics at Langley Field, Va. It is significant to note the increased application of American principles, not only in the design of aircraft, but also in the design and use of aeronautical research equipment. The value of investigations made at large scale is evidenced by the placing in operation in France, England, and Germany of wind tunnels of sufficient size to conduct full-scale investigations. The wind tunnels referred to are of the following throat sizes: England, 24-foot diameter; Germany, 17 by 35 feet; France, 52 by 26 feet. The latter is only slightly smaller than the Committee's full-scale wind tunnel at Langley Field, which has a throat size of 60 by 30 feet.

Gratifying development of American military and commercial type aircraft of high service performance and efficiency is largely the cumulative result of years of adherence to the sound governmental policy of sustained support of fundamental scientific research, a policy which started with the establishment of the National Advisory Committee for Aeronautics in 1915.

The greatly increased activity on the part of the major powers in building up their military air establishments and in extending their commercial air routes makes it evident that military supremacy in the air and the development and operation of trade routes of the air will be prime objectives of the strong and farsighted nations.

**Functions of the Committee.**—One essential of a national aviation policy for the United States falls particularly under the cognizance of the National Advisory Committee, and that is the long-range planning of fundamental research. The law provides that this Committee shall "supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions." This Committee is also authorized by law to "direct and conduct research and experiment in aeronautics."

One of the most important functions of this Committee is to correlate the research needs of aviation and prevent overlapping and duplication of effort. The National Advisory Committee for Aeronautics does not, however, have under the law the broad advisory functions which its name may seem to imply. Its primary function under the law is scientific research. A subordinate function, added in 1926, is to advise upon the technical merits of aeronautical inventions and designs submitted to any branch of the Government for Government use. Its major function of scientific research this Committee regards as the most fundamental activity of the Government in the development of American aeronautics.

**Committee's research facilities.**—Anticipating the research needs of aviation and with the farsighted and consistent support of the Congress, this Committee, in order effectively to discharge its responsibilities under

the law, has developed at Langley Field, Va., a well-equipped aeronautical research laboratory known as the Langley Memorial Aeronautical Laboratory. This laboratory is outstanding in the development of new types of equipment and new methods to extend the scope of fundamental researches in aeronautics.

At the present time the laboratories of this Committee comprise 12 structures and a research staff of 320 employees. Facilities for laboratory investigations and for researches on airplanes in flight are under the direct control of this Committee. Research equipment that is in large part unique makes it possible to obtain new knowledge not obtainable in any other country. The present equipment includes the full-scale wind tunnel, the seaplane tank, the propeller-research tunnel, the variable-density wind tunnel, a refrigerated wind tunnel, a vertical wind tunnel, an engine research laboratory, and a flight research laboratory. During the past year there have been placed in operation a new free-spinning wind tunnel and a 24-inch high-velocity jet-type wind tunnel. These two pieces of equipment were constructed with funds allotted by the Public Works Administration. The 8-foot, 500-mile-per-hour wind tunnel sometimes referred to as the full-speed wind tunnel, is nearing completion under a special allotment from the Public Works Administration. It is expected to be in operation early in 1936.

The Committee's laboratories are located on a portion of an Army field assigned to this organization by the Secretary of War and are under the direct control of the Committee. The cooperation of the War, Navy, and Commerce Departments with this Committee has been cordial and effective. This factor, combined with the status of this organization as an independent Government establishment, is largely responsible for the success of this Committee in meeting the research needs of the governmental agencies concerned.

**The Formulation of Research Programs.**—In the formulation of the Committee's research programs it is desirable and necessary either to know or to anticipate the research needs of the War, Navy, and Commerce Departments growing out of their plans for the future use of aircraft. In many cases specific investigations are requested of the Committee by these departments, based upon their actual or expected needs for new knowledge. Technical subcommittees organized along lines similar to the main Committee, including representatives of the governmental agencies concerned, also originate recommendations to the main Committee as to desirable researches to be undertaken. Suggestions for research are frequently received from the aircraft manufacturers and air transport operators. Researches authorized by the main Committee are usually

so broadened in scope as to make the results applicable alike to military and to civil aircraft.

The development policies and programs of the War, Navy, and Commerce Departments are largely dependent upon the successful prosecution of timely researches and special investigations by this Committee. This Committee does not engage in development. The engineering development necessary to adapt the results of research to practice is done by the agencies concerned and by the industry. In the Army Air Corps this is done largely by the Matériel Division at Wright Field. In the Navy it is done largely at the Naval Aircraft Factory at Philadelphia, and at the Washington Navy Yard. For civil and commercial aviation it is done by the manufacturers and operators.

This Committee also avails itself of the facilities of the National Bureau of Standards of the Department of Commerce for the conduct of certain types of investigations for which that Bureau is particularly well equipped, principally in the fields of physics and metallurgy. The facilities of universities are also utilized by this Committee.

**Trend of Development.**—The trend of development is in general toward larger airplanes with increased wing loading and aircraft engines of increased horsepower. Large airplanes, both of the landplane and seaplane types, offer the advantage of increased aerodynamic and structural efficiency. Many of the researches conducted during the past year had as their object the improvement of the aerodynamic and structural characteristics of large seaplanes and the improvement of engine and propeller performance.

Speed is one of the most important factors in increasing the relative importance of military airplanes and in extending the use of aircraft for commercial purposes. Within the past few years the cruising speed of military bombers and of transport airplanes has been nearly doubled. This marked advance is due in large part to the results of researches on the cowl-ing and cooling of radial air-cooled engines, and on the location of engine nacelles in multiengine airplanes, for the purpose of obtaining maximum propulsive efficiency and minimum resistance.

The outstanding performance of large airplanes constructed during the past year reflects the advancement made in engine development, both in increased horsepower and in supercharger performance. The successful development of the controllable-pitch propeller was also a factor. To increase further the speed of modern bombers and air transports, further study must be made to obtain: Improved engine-nacelle-wing and wing-fuselage arrangements; more satisfactory high-lift devices permitting higher wing loading; reduction of parasite drag; operation at high altitudes; and increased horsepower of present engines, or of similar

engines of the same weight and piston displacement. There is at present a strong indication of demand for the development of liquid-cooled engines of higher horsepower, from 1,000 to 1,500. This necessitates a study of the location of the radiator to obtain minimum resistance. The recent development of 100 octane fuel offers promise of materially increasing the horsepower of present engines and permits the use of higher compression ratios, resulting in reduction in fuel consumption.

Large airplanes will probably be either of the 2- or 4-engine type. The modern-type airplane, with its increased aerodynamic efficiency and high-speed characteristics, must be provided with a high-lift device to assure a safe landing speed. The problem of improving the take-off characteristics of a large airplane is just as important. A high-lift device should be effective in improving the take-off characteristics as well as in improving the landing characteristics. A number of promising devices investigated by this Committee, both in the full-scale wind tunnel and in flight, have been incorporated during the past year in large 2- and 4-engine airplanes.

In connection with this study the Committee has also investigated more effective means of lateral control that will permit the use of a high-lift device extending over the entire span of the wing and also provide better lateral control than is now afforded by the conventional wing and aileron.

The compression-ignition direct-injection type of aircraft engine has a place in the development of the long-range airplane, where fuel economy is of particular importance. The Committee has continued its investigations in this field of research, with results that give promise of the early development of an engine of this type in the United States.

The 20-foot wind tunnel and the full-scale wind tunnel at the Committee's laboratory have proved very effective in the study of propulsive efficiencies and in the reduction of resistance, so important in the development of the high-speed long-range airplane.

**The Light Airplane.**—In the development of the light airplane, or small, inexpensive, safe aircraft, provision must be made to incorporate in the design greater safety and improved economy. The solution of the problem of obtaining greater safety lies in the improvement of the take-off and landing characteristics. The landing must be slower so as to land safely within a restricted space. The take-off run must be shortened and the rate of climb increased so as to get out of a small area. The control, especially the lateral control, must be improved at the low speeds desired for take-off and landing.

This Committee has investigated in flight and in the full-scale wind tunnel new types of high-lift devices

and new means of lateral control on a light type airplane. The results of some of the investigations were incorporated in a light airplane known as the W-1, a pusher type, which at the request of the Bureau of Air Commerce was tested in flight and in the full-scale wind tunnel. This is the first airplane equipped with the N. A. C. A. slot-lip aileron, a new form of lateral control device which is satisfactory at low or stalling speeds. The device, however, has one disadvantage, in that the drag or resistance is high.

Much study and effort have been devoted to the development of a light airplane for the private owner, both in the United States and abroad. In the opinion of this Committee this development is of importance, as it will offer new and enlarged opportunities for the aircraft industry, and in effect create a new industry, with attendant opportunities for increased employment in connection with the production, maintenance, and servicing of such aircraft.

**General Discussion.**—The past year was notable as witnessing an appreciation by the nations of the world not only of the increasing value of aircraft as a means of national defense, but also as a means of communication and of extending commercial influence. One of the most significant factors in the development of world aviation is the enlarged appreciation on the part of the major powers of the fact that continued progress in aeronautical development must be based upon the conduct of scientific research. Several nations are recognizing in commercial aircraft development a desirable means of extending their commercial influence, with the result that long-range programs and plans are being formulated for the development of their commercial air services. The foundations are being laid now for a world-wide struggle for the control of trade routes of the air, and for the control of world aeronautical markets. It is becoming generally recognized that, other things being equal, a decisive advantage in this struggle will be with that country that has the greatest vision and initiative in establishing research facilities and in executing long-range research programs.

A significant and encouraging factor in the progress that has been made in aircraft in recent years is that, with improvement in performance, economic efficiency has also been increased. Contrary to experience in the railroad and automobile industries, the operation costs per passenger mile in aircraft have decreased with advances in speed. This Committee recognizes that the increase in speed of aircraft of approximately 100 percent during the past few years should properly be considered as progress above normal and at a rate that cannot be sustained. Nevertheless, further material improvements are confidently expected to result from efforts already under way, including: Improved

engine characteristics, based largely on the use of improved fuel; further fundamental investigations leading to further reductions in parasite resistance and in interference drag; improved propeller characteristics and increased propulsive efficiency; improved cowling and cooling of engines; and the placing of engines within the wings, which permits the efficient application of pusher propellers.

An adequate aircraft industry will be an absolute necessity in time of war. In time of peace a healthy nucleus of an aircraft industry capable of rapid expansion to meet emergency needs should be maintained. It should not continue to be so largely dependent upon Government orders and air-transport business as it has been. The development of private flying on a large scale would give stability to the industry. This would first require the design and production of aircraft which will be cheaper to build and easier to fly. The difficulties are fundamental, but it is the belief of this Committee that they can

be overcome by persistent effort and not otherwise. This Committee is giving serious attention to the technical problems involved in the development of the light airplane, and is also conducting researches on the problems incident to the development of small aircraft of rotating-wing types, such as the autogiro. In this connection, the large wind tunnels of this Committee have proved particularly effective, as the results obtained in small wind tunnels on rotating-wing types of aircraft are subject to large-scale effect errors.

Attention is invited to the reports of the technical subcommittees, which cover in more detail the technical progress in aeronautics made during the past year. It is the opinion of the Committee that continued liberal support of a well-planned and coordinated program of scientific research on the fundamental problems of aeronautics offers the only assurance of continuing the present leadership of the United States in the development of both military and commercial aircraft.

## PART I

### REPORTS OF TECHNICAL COMMITTEES

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In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These technical committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication.

As a result of a reorganization effected during the past year, the Committee now has three principal technical committees—the Committees on Aerodynamics, Power Plants for Aircraft, and Aircraft Structures and Materials—and under these committees nine subcommittees. The membership of these committees and subcommittees is listed in part II.

The Committees on Aerodynamics and Power Plants for Aircraft have direct control of the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the National Bureau of Standards. The greater part of the research under the supervision of the Committee on Aircraft Structures and Materials is conducted by the National Bureau of Standards. The experimental investigations in aerodynamics, aircraft power plants, and aircraft structures and materials undertaken by the Bureau of Aeronautics of the Navy, the Army Air Corps, the National Bureau of Standards, and other Government agencies are reported to these three committees.

#### REPORT OF COMMITTEE ON AERODYNAMICS

##### LANGLEY MEMORIAL AERONAUTICAL LABORATORY LANDING SPEED AND SPEED RANGE

The use of wing flaps has increased during the past year and the Committee has continued its investigations of the most promising forms, both in flight and in the wind tunnels. Most of the wind-tunnel work has centered about external-airfoil flaps and the appli-

cation of flaps to wings of different airfoil section. In addition, wind-tunnel work has been done on wings having boundary-layer control and wings having fixed slots. The flight work has dealt largely with the operation of the flaps and their effect on the performance and handling characteristics of the airplane.

**Full-Scale Investigation of Various Types of Flaps.**—A full-scale investigation of several types of wing flaps, including the Fowler, Zap, Cunningham-Hall, and external-airfoil flaps, has been started. Wings fitted with the various flaps are being mounted on the Fairchild 22 airplane and tested in the full-scale wind tunnel to determine their lift, drag, and pitching-moment characteristics, and in flight to determine the low-speed, take-off, landing, stability, and handling characteristics. The investigations in the full-scale wind tunnel have been completed for all except the external-airfoil flap and the flight investigations have been completed for the Fowler and Zap flaps. The Fowler flap used in this investigation has a chord equal to 30 percent of the wing chord and covers only the inner 71 percent of the span, conventional short, wide, slotted ailerons being used for lateral control. This wing is an example of a flap installation in which an attempt has been made to improve the high speed by reducing the wing area as well as to decrease the landing speed by the high lift obtained with the flap. The area with the flap retracted is only 77 percent that of the standard wing of the F-22 airplane, and the high speed is increased by 3 miles per hour. The increase in speed, however, is gained at the expense of the climbing characteristics, which are appreciably reduced with the smaller wing.

The Zap flap also has a chord equal to 30 percent of the wing chord but the wing has the same area as that of the original F-22 and the flap extends to the tips of the wing, Zap external ailerons being provided for lateral control. In order to avoid interference with the pilot and also to overcome tail buffeting, it was necessary to cut away the flap at the center portion of the wing so that it actually covered only 82 percent of the total span. With these differences in arrangement, both the Zap and Fowler wings give approximately the same maximum lift coefficient. The minimum drag coefficient of the Zap arrangement is

considerably greater, however, because of the external ailerons.

Both the Fowler and Zap flaps were found to be very effective in reducing both landing and take-off runs over a 50-foot obstacle. The landing distance was reduced by about one-third of its original value in both cases and the take-off run was approximately the same with both flaps. The deflection of the Zap flap had a very critical effect on the take-off run, however, a deflection of almost exactly one-fourth the full amount being required to give the best results, whereas with the Fowler flap any deflection within the last third of the travel gave about the same take-off distance. It should be pointed out that these take-off and landing performances depended not only upon the lift and drag of the wings but also upon the controllability and handling characteristics of the airplane.

**Flap Modifications.**—The external-airfoil flap, which consists of an airfoil pivoted at the rear of the main wing, has been investigated in considerable detail. An investigation has been made in the 7- by 10-foot wind tunnel with 3 main airfoils, the Clark Y, the N. A. C. A. 23012, and the N. A. C. A. 23021, each equipped with a cambered (Clark Y) external-airfoil flap. The results of this investigation, given in Technical Report No. 541, indicated that on the basis of their effect on airplane performance the best results were obtained with the N. A. C. A. 23012 main wing. The tests of this wing were then repeated with a flap also having the N. A. C. A. 23012 section. Inasmuch as this combination proved superior to the others, these tests were made not only to find the optimum hinge-axis location, considering lift and drag, but included also the flap-hinge moment and the air load on the flap.

At the request of the Bureau of Aeronautics, Navy Department, the Committee has investigated in the variable-density wind tunnel the N. A. C. A. 23012 and the N. A. C. A. 23021 airfoils, each equipped with external-airfoil flaps having the N. A. C. A. 23012 section. The flaps were located in the optimum positions as determined from results obtained in the 7- by 10-foot wind tunnel. The investigation in the variable-density wind tunnel at various Reynolds Numbers with the external-airfoil flaps and also with plain split flaps indicates that the scale effect on the lift increment given by the flaps is very small; that is, the increase in lift coefficient given by the flap at any particular setting is approximately the same for all Reynolds Numbers.

A number of confidential wind-tunnel investigations of flaps for special airplanes have been completed for the Bureau of Aeronautics.

**Quick Flap Operation for Control of Glide-Path Angle.**—The balanced split flap mentioned in the 1934 annual report has been used in flight investigations with a Fairchild 22 airplane to determine the effect of sud-

den operation of a flap on the motion of the airplane. A preliminary report of the results of these measurements has been submitted to the Bureau of Air Commerce and the final report is now in preparation.

The results of the investigation showed that where large changes in speed are involved, the initial effect on the glide angle when the flap is deflected is opposite to that desired. For example, with the airplane in gliding flight at low speed with flap extended, when the flap was suddenly retracted, the airplane dropped appreciably below the original glide path and did not rise above it until after a lapse of about 10 seconds. The reverse effect was observed when the transition was made from a flat glide with flap retracted to a steep glide with flap extended. The horizontal distance traveled during this transition period was about 800 feet and the vertical distance for the case involving sudden retraction of the flap was about 200 feet.

For the particular airplane used in the investigation the time required for operating the flap with the least violent motion of the airplane that could be made without sacrificing distance in obtaining the desired change in glide path was about 6 seconds. When the elevator was used in such a manner that the operation of the flap involved no speed change, the desired change in glide angle was obtained very quickly. In order to make this type of maneuver it was required, of course, that the speed be greater than the minimum obtainable with flap retracted and that the change in lift coefficient resulting from a change of flap position be compensated by a change in angle of attack. With the control stick free the airplane used in these tests tended to trim at different speeds with changes in flap position, so that in making the transition from one glide angle to another without a change in speed it was necessary for the pilot to coordinate the elevator movement with the flap movement.

A flap arrangement suitable for direct and instantaneous control of the glide-path angle has been incorporated in the Weick W-1A airplane, the characteristics of which have been investigated in flight at the request of the Bureau of Air Commerce. The airplane is arranged to trim at approximately the same air speed with the flap at any deflection between 23° and 60°, the range used for the landing operation. It was found that a satisfactory approach to a landing could be made with this flap arrangement, the glide angle being adjusted without change in speed as required to make contact at a desired point on the ground.

A preliminary investigation has been made in the 7- by 10-foot wind tunnel for the purpose of obtaining a flap arrangement especially suitable for installa-



tions of this nature providing direct and instantaneous control of the steepness of the glide path. Such a flap has been developed giving a reasonably high lift coefficient with relatively low deflection and maintaining this value of the maximum lift coefficient with a large increase of deflection. In this arrangement the increase in deflection is accompanied by a large increase in drag but a small change of pitching moment. The results of this work will be published in a report now in preparation.

**Boundary-Layer Control.**—The study of the possibilities of boundary-layer control, started about 2 years ago, has been continued with tests of 2 additional wings in the 20-foot wind tunnel. The first of these wings was a normal rectangular airfoil 15 percent thick. (The previous investigation was made with a wing 30 percent thick.) The results indicated that a more forward location of the suction slot was desirable than had been found most effective for the extremely thick airfoil. Owing to the somewhat more restricted area inside the 15-percent airfoil, a much greater blower power was required to produce a given lift. In an attempt to reduce the blower power required, a tapered wing was constructed to provide, in effect, a tapered duct having an increase in the cross-sectional area available from the tip to the center. Considerable reduction in blower power was obtained with the tapered wing, but the power was still greater than that required with the extremely thick wing.

The results to date indicate that the high power required is due primarily to the loss occurring within the wing. No difficulty has been experienced in maintaining the flow up to angles of attack of  $50^\circ$ , and lift coefficients of 5 or 6 are attainable if sufficient power is available. Several methods to reduce the internal loss have been suggested and some of the more promising are to be investigated.

Although the main object of the investigation to date has been to increase the maximum lift coefficient, consideration is now being given to the reduction of drag by means of boundary-layer control. A study is planned on very large airfoils in which the boundary layer will be investigated in detail, and in which several schemes for keeping the boundary layer laminar will be tried.

**Fixed Slots.**—A type of fixed open slot so arranged that no flow would pass through it at a lift coefficient corresponding to high-speed flight was investigated in the 7- by 10-foot wind tunnel to determine the possibilities of such a high-lift device for increasing the speed-range ratio of a wing. The condition of no through flow was achieved by locating the slot openings at points of equal static pressure at the desired lift coefficient as determined by the pressure distribution about the plain wing. The results of this in-

vestigation (Technical Note No. 507) showed that the condition of no air flow through the slot at the desired lift coefficient was attainable, but that the surface discontinuities produced by the slot openings had such a large adverse effect on the drag that such slots show little promise.

#### CONTROLLABILITY

The Committee has for some time been carrying on a program of research on lateral control, with the particular purpose of obtaining information leading to improvements of control at low speeds and high angles of attack through the stall, a region in which the present ailerons are known to be unsatisfactory. Several wind-tunnel investigations have been conducted and an attempt has been made to compare a number of widely different lateral control devices on the basis of what has been considered their primary function, the extent of rolling moment provided. Some of the secondary characteristics, such as the yawing moments given by the control devices and their effect on the damping in roll, had been considered in the early part of the work, but only by comparing the various values separately.

Some of the devices that seemed to promise the best control at the stall were then investigated in flight. It was found that the devices did not always perform as had been expected from the wind-tunnel results, indicating that the first approximation based largely on the rolling moments given by the devices was an insufficient basis for satisfactory comparison, and that the complete interaction of the secondary factors must very likely be considered.

A study has recently been made by means of computations taking into account all the secondary factors including the yawing moments given by the controls, their effect on the damping in roll, all the other lateral-stability derivatives, and the airplane moments of inertia. The computations consist of step-by-step solutions of the equations of rolling and yawing motion for the conditions following a deflection of the controls, and for entering, maintaining, and recovering from turns. The results of these computations based on aerodynamic data obtained from the wind tunnel agree satisfactorily with the results measured in flight for widely different forms of control, such as ailerons and spoilers.

The computations have also been made for the stalled-flight condition, for which the actual values of the stability derivatives are very difficult, if not impossible, to obtain with reasonable accuracy and for which the flight results are necessarily merely qualitative because the performances could not be closely repeated. The results agree with the qualitative results of the flight tests. This method not only makes

possible the computation of the airplane motions to be expected in flight following a deflection of the lateral controls but also aids in determining what relations between rolling moments, yawing moments, and airplane stability characteristics are most desirable for good controllability.

Similar computations have been used to determine the stability derivatives and the control moments that would be most desirable for performing maneuvers, particularly turns, in an airplane equipped with only two controls, i. e., elevator and ailerons only, or elevator and rudder only.

In connection with this work a method of solving the equations of motion by means of operational calculus has been devised that should be useful in solving various problems concerning the dynamics of airplane flight, including such factors as the effect of gusts. Reports on all three of these analytical studies are in preparation.

**Slot-Lip Ailerons.**—In previous years an improvement in lateral-control moments was found to be given by flaps known as "spoilers" projecting from the upper surface of the wing, but when these devices were tried in flight they were found to have a lag in action that made them unsuitable for use. An investigation of means for eliminating this lag, conducted in the 7- by 10-foot tunnel on a model wing having a 4-foot chord, has resulted in a new form of lateral control device which has been termed the "slot-lip aileron." This device is a combination of aileron-type flap and a continuously open slot, the flap forming the upper portion or lip of the slot. It appears to be usable as a form of lateral control device, showing promise of improved control and stability at the high angles of attack through the stall, with negligible lag, low control forces, and relatively simple construction. Tests on a standard-size model (10 inches by 60 inches) in the 7- by 10-foot tunnel with the slot-lip ailerons located in three different positions along the chord of the wing, showed that with the original slot design the drag was high, particularly with the aileron in the forward position. Slot-lip ailerons have been investigated in flight on the W-1A airplane and in that case were found to give satisfactory control. A more extensive flight investigation is planned with the F-22 airplane for which a wing is now being fitted with slot-lip ailerons in two different chord positions. In addition, tests have been initiated on a large-chord model in the 7- by 10-foot tunnel, in which the possibilities of reducing the drag of the slot-lip ailerons will be studied.

In one version of the slot-lip aileron the front and rear portions of the wing each have the appearance of an individual smoothly formed airfoil, the slot-lip aileron being merely a flap of the usual aileron type forming the trailing-edge portion of the front airfoil.

The rear airfoil can then be deflected downward for high lift, forming in effect an external-airfoil flap. An investigation has just been completed in the 7- by 10-foot wind tunnel on a model having an arrangement of this type.

**External-Airfoil Flaps Deflected as Ailerons.**—In a previous investigation, the results of which were published in Technical Report No. 541, external-airfoil flaps were themselves deflected differentially as lateral control devices. The tests were made with the flaps divided at the center so that each aileron formed half the entire flap, and also with the flaps cut at points one-half the semispan from each tip, in which case the center half was used solely as a flap and the tip portions were used as both ailerons and flaps. One of the arrangements having the flap cut at the center of the span, the two halves being deflected as ailerons with a differential linkage and having neutral settings as a flap varying between 5° up and 20° down, was selected as the best of those considered. A wing with this arrangement is being constructed for investigation in flight on the F-22 airplane.

**Flight Investigation of Lateral Controls for Use with Flaps.**—The flight investigation of lateral controls for use with flaps has been continued in conjunction with a full-scale investigation of a series of high-lift wings. The results of the earlier flight investigations relating to lateral control devices for use with full-span flaps have been published in Technical Report No. 517. In the series of wings now being investigated, tests have been completed of short, wide, slotted ailerons in conjunction with a Fowler flap and of Zap external ailerons in conjunction with a Zap flap, both fitted to the F-22 airplane. The ailerons on the Fowler wing appear to be satisfactory for the F-22 airplane on which they are installed except for a tendency for the control forces to become too great at high speeds. Two sizes of Zap ailerons have been tested in connection with the Zap flap, one having a chord equal to 18 percent of the wing chord and the other 22 percent of the wing chord. The difference in chords is compensated by a difference in span to make the areas equal. Both of these ailerons were very effective in providing lateral control, even at low speeds, but they have two serious disadvantages in that they add considerably to the drag of the airplane and that the force required to operate them becomes excessive at high airplane speeds.

**Tabs.**—A report has been prepared (Technical Report No. 528) concerning a wind-tunnel investigation of the aerodynamic characteristics of tabs, or small hinged flaps, on control surfaces. The tabs may be used to trim airplanes in flight and also to reduce the force required to operate the controls. Because of a demand for information suitable for stress analysis and

design, determination of the pressure distribution was made in the 7- by 10-foot wind tunnel on a wing model equipped with an aileron and tab. The resulting pressure-distribution diagrams were integrated for total normal force of wing with aileron and tab, normal force and hinge moment of aileron with tab, and normal force and hinge moment of tab alone. A report is now in preparation on the results of this investigation.

**Magnitude of Control Force Available.**—A report has been completed on the work mentioned last year in which an arrangement simulating a pilot's cockpit with controls was constructed and measurements made of the forces that could be exerted on the control column and rudder pedals with the airplane in various attitudes and the controls in various positions. Both the forces that could be comfortably exerted and the maximum forces that could be applied were determined.

#### STABILITY

Experience has shown that various flaps have considerable effect on the stability of an airplane aside from any consideration of tail-plane setting. Wind-tunnel results show that the flaps introduce great increases in the negative pitching moment, the amount depending on the type of flap as well as on the increase of lift attained. On the Fairchild 22 airplanes used in the investigation of various types of flaps, the large pitching moments introduced a condition of static longitudinal instability with the stick free. In some cases it was necessary to correct this condition before proceeding with the flight investigation. A preliminary study of tail-surface design in connection with flapped wings indicates that, whereas with normal wings the criterion of the required tail area for stick-free static stability is the rate of change of wing pitching moment, with flapped wings the magnitude of the moment is of equal importance. The directional stability is also adversely affected by the addition of flaps, at least for the parasol monoplane arrangement, for which the blanketing of the fin and rudder is appreciable and the stabilizing effect of the vertical surfaces is reduced.

In addition to these more or less definite effects of the flaps on stability, there is apparently a condition of unstable air flow present with flaps deflected, and any slight roughness of the atmosphere produces disturbances to the airplane of considerably greater magnitude with than without flaps. The condition is unpleasant but does not appear to be dangerous. The disturbances set up may be about any of the three axes of the airplane. To improve this condition, the effect of increasing the dihedral was investigated in flight. The dihedral angle was varied from 0° to 9°.

The smaller dihedral angles did not have an appreciable effect on the unstable condition. Higher angles introduced, of themselves, a type of lateral unsteadiness similar to that resulting from the flap but of greater magnitude, so that at a dihedral angle of 9° it was impossible to separate the two effects.

A report (Technical Report No. 521) presenting a series of working charts from which dynamic longitudinal stability in power-off flight can be readily estimated has been published.

An analysis of data obtained in an investigation of the longitudinal stability characteristics of several airplanes, which was undertaken for the purpose of determining the degree of stability desired for good flying qualities, has been completed. Within fairly wide limits of dynamic stability the force required to operate the controls is more important than the degree of stability in determining the pilot's impressions of the flying qualities of the airplane.

#### TAKE-OFF

The results of an analytical study of the effect of various high-lift devices on take-off have been incorporated in a paper being prepared for publication.

An investigation of the rolling resistance of a number of airplane wheels has been completed and the data are now being analyzed. As noted last year, this investigation was made with a two-wheel carriage towed by a truck. Drawbar pull, speed, and acceleration were measured on different surfaces, with variations in weight and tire pressure. Six pairs of airplane wheels and tires were tested, including two sizes of each of three principal types of tires—high-pressure, low-pressure, and extra low-pressure. The results indicate that the rolling resistance on firm turf is roughly twice as great as on concrete; on a relatively soft field the resistance may be as much as four times as great as on concrete. There is a definite increase in the rolling-resistance coefficient with increasing loading and also with decreasing tire-inflation pressure. Apparently there is little or no difference between the resistance for different sizes of the same type of tire. For all types and conditions there was evidence of some variation in resistance with speed, generally increasing slightly with speed at the lower speeds and decreasing somewhat at the higher speeds.

#### SPINNING

The 15-foot free-spinning wind tunnel has been completed and placed in operation. Following tests of models of two airplanes for which the spinning characteristics are well known, the tunnel is being used for testing models of airplanes of which the spinning characteristics are either unknown or known to be unsatisfactory. The models of the two airplanes

for which direct comparisons are available were found to spin in slightly different attitudes from the airplanes for given control settings, but would apparently achieve a steady spin with any control setting that resulted in a full-scale steady spin. Recovery tests showed surprisingly close agreement between model and airplane. Tests with a third model, for which some full-scale results are available, also gave very good agreement. All these models represented staggered biplanes of service type, and it seems advisable that comparisons be made between model and airplane characteristics for a high-wing and a low-wing monoplane. Steps are being taken to make such comparisons.

Since completion of the tunnel, 7 models have been tested, 4 of which are scale models of service airplanes and 1 of which resembles a particular service airplane in dimensional characteristics, but not in mass distribution. These models have consistently confirmed the opinion previously held that the most important single factor affecting spinning characteristics, particularly recoveries, is the amount of unshielded vertical fin area at the tail. In one case, the addition of an unshielded vertical fin with an area less than 5 percent of the original area, which was badly shielded, made the difference between complete failure to recover and fairly satisfactory recoveries.

Each of two models of airplanes with retractable landing gears showed decided improvement in recovery characteristics when the gear was retracted, compared with the characteristics with the gear extended. In the case of one of these models, failure to recover with the gear extended changed to two-turn recoveries with the gear retracted.

For some of the models it has been found that, for a given control displacement, the recovery characteristics depend very greatly upon the sequence and quickness of operation of the controls. Repeated cases have occurred for which satisfactory recoveries were obtained when the elevator and rudder were simultaneously reversed or when rudder reversal was followed by elevator reversal but for which no recovery was obtained if the elevator was reversed first. Cases have also occurred in which quick motion of the controls brought immediate recovery but in which very slow motion resulted in a new steady-spin equilibrium.

A report on the spinning of the full-scale F4B-2 airplane has been published (Technical Report No. 529). The work reported includes determination of the effect of: Moderate changes in mass distribution, large increases in fin and rudder area, raising the horizontal tail surfaces, changing the plan form of the elevator, increasing the maximum travel of the rudder, and various methods of using the controls during the spin and for recovery. Brief reference is also made

to the dimensions and operating technique for a parachute mounted at the tail of the airplane to be used in case recovery should be impossible when using the airplane controls. The aerodynamic forces and moments on a model of the F4B-2 airplane have been measured on the spinning balance in the 5-foot vertical wind tunnel and the results have been published in Technical Note No. 517.

In order to complete the extensive information already obtained on the Fleet training biplane, tests of turns required for recovery were made under all conditions likely to be of interest for comparison with the reactions of the model of this airplane in the free-spinning wind tunnel. The recovery motion was observed by the pilot and by observers in another airplane flying near the point of recovery. Motion pictures were made of some of the recoveries for comparison with similar photographs of the model made in the free-spinning wind tunnel.

Investigations have been continued with the spinning balance in the 5-foot vertical wind tunnel to obtain fundamental information on the magnitudes of the forces and moments produced by the wings alone. In these investigations the six components of air forces and moments are measured for the entire ranges of angle of attack, rate of rotation, and angle of sideslip likely to be encountered in spins. One report (Technical Report No. 519) has been prepared on an investigation on the spinning balance of a rectangular Clark Y monoplane wing, and another (Technical Note No. 526) on an investigation on the spinning balance of a rectangular Clark Y biplane cellule having 25 percent stagger, zero decalage, and a gap-chord ratio of 1.0. It is planned to continue these investigations with other biplane cellules having various gaps and staggerings.

An extensive investigation is being started on the spinning balance with a model of the Fleet biplane to make possible a complete comparison of spinning-balance, free-spinning tunnel, and flight data on the spinning characteristics of this airplane.

#### DRAG AND INTERFERENCE

The marked increase in the flying speeds of all types of airplanes in recent years has been made possible largely by decreasing the drag of the component parts of the airplane by reducing the number of protuberances from the primary parts of the airplane and by reducing the unfavorable interference effects between those parts.

Inasmuch as it is believed that substantial further gains are possible in the same direction, systematic investigations of interference effects have been continued throughout the year in some sections of the

Committee's laboratory, and incidental studies with a view to reducing the drag of various airplane parts have been conducted from time to time in other sections.

**Drag of Component Parts.**—A comparison of the drag of several types of rivet heads on a wing of 5-foot chord in the 7- by 10-foot tunnel indicated that the shapes of rivet heads exposed to the air flow had little effect on the drag, that countersunk dimpled rivet heads were about as objectionable as the exposed type, and that the flush-type head gave a measurable improvement.

An investigation in the full-scale wind tunnel on a mock-up of the YO-31A airplane to determine the drag of the prestone and oil radiators shows that, even on an airplane having as clean a radiator installation as the YO-31A, the radiators may account for about 12 percent of the drag of the complete airplane; the prestone radiator alone accounts for more than 8 percent and the oil radiator alone for about 3 percent of the drag.

**Wing-Fuselage Interference.**—The importance of aerodynamic interference in relation to the improved speed and efficiency of the modern airplane is now well known. The general investigation of aerodynamic interference being conducted in the variable-density wind tunnel has been concerned for the past year with the interference between the wing and the fuselage.

The first and largest phase of this program has been completed and the results are being published as Technical Report No. 540, which constitutes a comprehensive study of the subject, including the results of tests of 209 different combinations of wings and fuselages. Important favorable interference effects are usually the result of drag saved by enclosing a considerable part of the wing surface within the fuselage. Marked adverse interference effects are associated with a breakdown of the flow near the wing-fuselage juncture. This phenomenon, referred to as "the interference burble", is a complicated one dependent on the stability of the flow over the particular airfoil used and the conditions at the wing-fuselage juncture. Efficient airfoils of moderate thickness and low camber are most susceptible to such adverse interference. The interference burble does not necessarily affect the maximum lift coefficient.

The program is now being extended to complete the investigation of combinations having a fuselage of elliptical section and of combinations having a wider variety of wings than were originally investigated, particularly wings fitted with various high-lift devices.

The investigation of wing-fuselage interference being made in the full-scale tunnel on the mock-up of the YO-31A airplane has been completed for the parasol positions of the wing. The results show that

there is little choice between a wing position at the top of the fuselage and one ranging to 18 inches above the fuselage. The decrease in interference drag as the wing is raised is offset by the increase in strut drag.

**Wing - Nacelle - Propeller Interference.**—The mutual effect of wing, nacelle, and propeller has been determined for most practical cases in an extensive investigation in the propeller-research tunnel. The results have been presented in a series of six technical reports supplemented by several technical notes. Although the research has not been as intensively prosecuted during the past year as previously because of the urgency of other work, several experimental studies have been made.

Technical Report No. 507, dealing with pusher propellers behind cowled radial-engine nacelles, indicated good propeller efficiency but high nacelle drag. If the drag could be reduced the pusher nacelle-propeller arrangement would appear more favorable. Accordingly, several tests were made of models with different cowlings shapes for radial engines with which pusher propellers could be used. Scarcely any improvement over previous results was obtained, because of the blunt shape of the rear part of the nacelle necessitated by the proximity of the propeller to the cylinders. When a spinner was used to improve the shape, the suction of the rotating slipstream apparently increased the drag. Altogether, the pusher propeller driven by a radial engine is not efficient. A carefully cowled radial engine well forward of the propeller with an extension driving shaft seems to be the only practicable arrangement. The possibilities of this scheme were suggested 2 years ago, but no comparative data have been obtained. A short series of tests comparable with those of other combinations is being made.

The increasing use of in-line engines, especially of the smaller powers, indicated a need for more information regarding nacelles suitable for this type of engine and their position relative to the wing and propeller. An investigation has therefore been made with a representative nacelle located near the leading edge of the thick wing used in some of the early work. A position directly ahead of the leading edge gave the highest efficiency, but the propeller could be located somewhat closer to the wing than the position required for the radial engine. The drag and interference for small powers (below 300 horsepower) were found to be slightly higher than for radial engines. Above 300 horsepower the in-line engine should have the advantage, inasmuch as a 300-horsepower in-line engine has practically the same frontal area as a 90-horsepower in-line engine; whereas the cross-sectional area of the radial engine increases with power.

Further study of wing-propeller-nacelle combinations with in-line engines, but with pusher propellers,

is to be made in the next few months. These model tests are to be supplemented by tests of various cowlings on an actual in-line engine to determine the cowl shape best suited to low drag and satisfactory cooling.

Study of the existing data indicates that the cowed radial engine in the best location accounts for about 10 percent of the drag of modern transport airplanes that have a top speed of about 200 miles per hour. It is apparent that this parasite drag must be reduced if higher speeds are to be obtained without considerable increase of power. One of the most obvious possibilities is the housing of the engine in the wing with an extension shaft to the propeller. A few experiments simulating this arrangement have been made. They indicate that, although the arrangement with an extension shaft to the rear driving a pusher propeller shows slightly higher propulsive efficiency than was shown by tractor propellers, the gain in efficiency is more than offset by the higher drag of the particular shaft housing tried. It may be practicable to reduce the diameter of the housing and further investigation with a smaller housing is contemplated.

The model tests thus far made have not included a radiator or other device necessary to cool the engine. The evidence now available shows that a radiator of the type projecting into the air stream may alone account for about 12 percent of the airplane drag and, unless improvements are made in it, the engine in the wing with an extension shaft offers no advantage over the cowed radial engine. Recent results of the investigation of radial-engine cowling point to the possibility of reducing the drag of a radiator by a carefully designed cowling, and the appraisal of the engine-in-wing scheme must await the solution of the engine-cooling problem with a low-drag radiator.

In most multiengine airplanes the nacelles are located on the wing and there may be additional interference from the proximity of the fuselage. An investigation with a model of a complete airplane to determine this effect has been made by moving the nacelles various distances from the fuselage. The results were in reasonable agreement with previous results with the nacelle located in the center of a plain wing.

#### COWLING

As stated in previous reports, a systematic study of engine cowling and cooling is proceeding in three main parts: (1) the determination of the cooling requirements of an air-cooled engine; (2) the finding of the best cowling arrangement to obtain the necessary cooling with minimum drag; and (3) the verification of the results of parts (1) and (2) by tests on complete full-size engines. Parts (1) and (2) have proceeded to such a point that the third part of the investigation—

tests of a Wasp S1H1-G engine, kindly loaned by the manufacturer—was started a few months ago. The agreement between the results of parts (1) and (2) and part (3) is, in general, quite good. In the course of the tests on the actual engine, a number of new phenomena were discovered by extensive velocity measurements and smoke-flow studies. Certain differences between the test conditions on the actual engine and the model were discovered, and some additional work on parts (1) and (2) is required, as well as additional engine tests, before recommendations as to cowling design can be prepared. The tests of the actual engine show the quite remarkable efficiency of the correctly designed N. A. C. A. cowling and will be carried on until the essential design factors have been established.

It was found that relatively minor changes in the shape of the leading edge had a large effect on the drag of the cowling and that also, in general, an increase in the quantity of cooling air increased the drag proportionally. The proximity of the propeller was also found to exert an influence. An installation in the propeller-research tunnel that permits the actual determination of the cowling and propeller efficiency is being completed at the present time. In this installation the engine cowling is completely detached from the nacelle and propeller, permitting the direct measurement of the drag of the engine-cowling unit and, incidentally, permitting the measurement of the true propeller efficiency. The main object of this particular investigation is to obtain design information on the aerodynamic properties of the N. A. C. A. cowlings.

#### PROPELLER DESIGN

The increase in the speed of airplanes has rendered inadequate the existing data on propellers. The investigation of full-size metal propellers at pitch settings up to  $27^\circ$  was well above any requirements at the time it was made. Recent transport designs are using pitch settings of  $35^\circ$ . As a preliminary to a more extensive study, tests were made with an N. A. C. A. cowed nacelle-and-wing combination and a 4-foot propeller with a series of settings up to  $42^\circ$ . The results of these tests, which will be published soon, show that the maximum efficiency is reached at a setting of from  $28^\circ$  to  $32^\circ$ . The particular propeller used was designed for low pitch; at high pitch settings the pitch distribution is not the best, and may partly account for the lack of efficiency above the  $32^\circ$  setting.

Most propellers in use in this country have either the Clark Y or modified R. A. F. 6 airfoil sections. The superiority, in most respects, of the modified R. A. F. 6 airfoil was pointed out some years ago. A study of airfoils in the high-speed wind tunnel has indicated, however, that there may be some advantage in certain other sections. At the request of the Bureau

of Aeronautics, Navy Department, an investigation of full-scale propellers is being planned to include new airfoil sections, modern plan forms, different pitch distributions, higher pitch settings, and two and three blades. The program is expected to settle simultaneously a number of propeller questions and to provide information useful in the analysis of present and future designs. As a preliminary to this investigation, a comprehensive analysis of design requirements under widely varying conditions of power, rotation speed, altitude, etc., is being made. The results should indicate the proper design trends for best results and may show methods of overcoming the low efficiency now occurring in certain ranges of propeller operation.

#### PROPELLER NOISE

A detailed study of the noise emission from an 8½-foot propeller has been completed (Technical Report No. 526). This work showed the distribution of sound in various directions about the propeller and the extent to which the ear responds to this distribution in recognizing loudness. Estimates were made of the total power output in sound.

Similar measurements have been made on full-size propellers of various diameters, thickness ratios, section shape, and numbers of blades. The results show that the original division of the sound into the rotation noise (roar) and vortex noise (swish) is a logical one because the two groups of sounds obey quite different laws. The results also show how different frequency bands determine the loudness of the noise in different directions and at different distances.

In order to obtain information regarding vortex noise by itself, without the accompanying rotation noise, a study was made of the sound from rotating cylindrical rods (Technical Note No. 519). This sound consists almost exclusively of vortex noise and much valuable information was secured from this study. It showed among other things that the von Kármán formula for the frequency of vortex emission holds for simple shapes like cylinders at audible frequencies.

The N. A. C. A. sound analyzer has been continuously improved to assist in research into the nature of propeller noise. The design of this analyzer is radically different from any heretofore devised; its development was made necessary by the transient nature of the phenomena involved in propeller noise. The frequency band passed by the present analyzer is continuously variable.

It was suspected, owing to the type of wave emitted from a propeller and the known unsymmetrical response of the ear to sounds of high intensity, that certain peculiar subjective effects would take place

close to a propeller. These effects were found to occur and the results of the investigation were published in the *Journal of the Acoustical Society of America* for October 1934 under the title "Aural Rectification."

#### AIRFOILS

The development of an improved basic airfoil section as the result of investigations of a large number of related airfoils in the variable-density wind tunnel was mentioned last year. The results of the investigation of related airfoils having the maximum camber at a point unusually far forward, which is the phase of the work recently completed, are being published in Technical Report No. 537. The new section, referred to last year as the N. A. C. A. A-312 and since designated the N. A. C. A. 23012, has been further investigated during the year by testing a large wing having this section in the full-scale wind tunnel. The results from the full-scale wind tunnel confirmed the excellent characteristics of this airfoil as indicated by the results from the variable-density wind tunnel; in fact, the comparison with conventional sections is even more favorable to the new section when based on the data from the full-scale tunnel than when based on the variable-density-tunnel data (Technical Report No. 530).

The investigation of airfoil sections in the variable-density wind tunnel has also been extended to study the possibilities of improving the new section. Thirteen additional airfoils varying geometrically in several directions from the N. A. C. A. 23012 have been investigated. The variations consisted of changes in the leading-edge radius, the maximum thickness, the position of the maximum thickness, the maximum camber, and the position of the maximum camber. The results confirm the original findings that the best position for the maximum camber is at 0.15 of the chord from the leading edge, corresponding to the maximum-camber position for the N. A. C. A. 230 mean line. Reports giving the results of this work are in preparation.

**Tapered Wings.**—In connection with an investigation of wing-fuselage interference, an investigation was made in the full-scale wind tunnel on a tapered wing of the U. S. A. 45 section having a span of 46 feet, built to fit the YO-31A airplane. Pressure-distribution measurements as well as force measurements were made on this wing and the scale effect was studied by making the tests at different air speeds. (See Technical Note No. 521.)

The tests in the variable-density wind tunnel of tapered airfoils with sweepback and twist, mentioned in the 1934 annual report, have been completed. The investigation of tapered wings is being continued by



the preparation of data for the analytical determination of the characteristics of tapered wings based on the experimentally determined characteristics of the wing sections. A new series of tapered airfoils is being built for test at the request of the Army Air Corps.

An investigation of rectangular airfoils with rounded tips requested by the Army Air Corps has also been completed. The results indicate that existing wing theory is inadequate to account for the experimentally observed differences between rectangular and rounded-tip wings. The data have, however, provided empirical corrections that may be applied to data obtained from tests of rectangular airfoils to obtain more reliable airfoil section characteristics.

**Scale Effect.**—The investigation of airfoil characteristics as influenced by scale effect has been included during the year particularly in the program of the variable-density wind tunnel, which is especially adapted to this type of investigation. Such investigations, which have formerly been of value mainly for the interpretation of small-scale model tests, have proved to be of primary importance because airfoil characteristics have been found to vary considerably within the full-scale range of values of the Reynolds Number and because even the largest wind tunnels cannot attain the large dynamic-scale values associated with large modern high-speed airplanes.

The scale-effect investigation may be subdivided into three phases: (1) Investigation of the fundamental nature of the phenomena; (2) investigations dealing with turbulence and the interpretation of wind-tunnel data; and (3) the measurement, classification, and interpretation of actual scale effects from tests of models in the variable-density wind tunnel. The study of the fundamentals of the phenomena is, in fact, mainly in an investigation of the boundary layer, inasmuch as scale effects result directly or indirectly from changes in the character of the boundary layer with variations of the Reynolds Number. The investigation of the boundary layer is directed toward gaining an understanding of its behavior as regards the skin friction of the laminar and turbulent layers, the separation of the laminar and turbulent layers, and finally the transition from the laminar to the turbulent layer. Fairly satisfactory methods of analysis of the skin friction of the laminar layer are available; an analysis of the separation of the laminar boundary layer is given in Technical Report No. 504. During the year the accuracy of this method of analysis was investigated by comparing the calculated separation point of the laminar boundary layer of an elliptic cylinder with experimental results obtained at the National Bureau of Standards (Technical Report No. 527). The comparison indicates that the method of calculating the laminar-layer separation is satisfac-

tory provided that data experimentally determined on the pressure distribution are available.

Another phase of this work is concerned with the theoretical potential-flow pressure distribution as affected by the presence of the boundary layer. This subject is being investigated by a comparison of very carefully measured pressures about the N. A. C. A. 4412 airfoil in the variable-density wind tunnel with pressure distributions from potential-flow calculations. It appears that the observed differences are such as might be expected to result from the neglect of the frictional layer in the "ideal fluid" or potential-flow theory. A method of correcting the calculations from the potential-flow theory will be included in a report now in preparation. This method permits the pressure distribution about airfoil sections to be calculated with greater accuracy than has heretofore been possible.

The turbulent boundary layer has not proved to be as susceptible to analysis as the laminar layer but semiempirical analyses of some value are available. From the standpoint of those studying scale effect, the phase of the problem dealing with the nature of the transition region as affecting separation and the succeeding turbulent layer appears to be of the greatest immediate importance. In fact, the marked scale effects that have been observed experimentally appear to be largely dependent on the transition of the laminar to the turbulent layer. The investigation of the transition is being started by means of smoke-flow observations in the smoke tunnel and in flight. During the year some of the smoke-tunnel moving pictures have been assembled as Technical Film No. 2, which is now available for loan.

Finally, the required engineering data on scale effect are being largely obtained from tests in the variable-density wind tunnel and by comparisons of airfoil tests in the full-scale wind tunnel, in the variable-density wind tunnel, and in the smaller atmospheric wind tunnels. The main investigation has consisted of tests of a variety of related airfoil sections in the variable-density wind tunnel over a wide range of values of the Reynolds Number. The investigation will eventually include also airfoil sections with various high-lift devices. The most notable result is the conclusion that airfoils may be classified with respect to the character of their maximum-lift scale effect. Well-known and commonly-used airfoils have been thus classified and a report on scale effect now in preparation will give the various scale-effect functions so that the data on any airfoil that has been classified, as indicated in the standardized tabulation of its important aerodynamic characteristics, may be easily corrected for scale effect.

**Aerodynamic Effects at High Speeds.**—Investigations of the aerodynamic phenomena encountered at high speeds, or the so-called "compressibility effects", are



of importance mainly in relation to the adverse effects on propellers having high tip speeds although, with the increasing speeds of modern airplanes, compressibility effects are beginning to be significant for the wing and other component parts of airplanes as well. The Committee's investigations of high-speed phenomena have been greatly assisted during the past year by the addition of the new 24-inch high-speed wind tunnel in which airfoils of 5-inch chord may be tested.

The air flow associated with the abrupt detrimental changes in airfoil characteristics observed as the air velocity approaches the velocity of sound was referred to in the 1934 annual report as the "compressibility burble" but little was then known of the fundamental nature of the phenomenon. An investigation of the compressibility burble has been conducted in the 24-inch high-speed wind tunnel. Simultaneous Schlieren photographs and pressure-distribution measurements of the flow about an N. A. C. A. 4412 airfoil have been made to determine the physical character of the "compressibility burble."

The results obtained indicate the following possible explanation of the flow phenomenon. As the free-stream air speed approaches the velocity of sound, the air in passing over the airfoil surface is accelerated to speeds in excess of the local velocity of sound and, when this condition occurs, a compression shock is formed that involves a more or less sudden, rather than a gradual, retardation of the flow and a dissipation of energy. The source of the increased drag observed at the compressibility burble is the compression shock and the excess drag is due to the conversion of a considerable amount of the air-stream kinetic energy into heat. The compressibility burble appears when the velocity at any point in the flow equals or exceeds the velocity of sound. A report covering this investigation is being prepared.

#### THEORY OF PRESSURE DISTRIBUTION

The study of the potential flow about elongated bodies of revolution has been completed and the results presented in Technical Report No. 516. The method has since been extended to include the theoretical determination of the pressure distribution over airship shapes in curvilinear flight.

A general study of compressible flows has been started. The investigation has been limited to velocities in the neighborhood of that of sound where the flow may still be described by a velocity potential. Thus far, the various theoretical methods devised by G. Braun, L. Poggi, and Lord Rayleigh have been applied to simple shapes like a cylinder and a sphere in order to obtain some knowledge of their relative merits and the further applicability to the flow about airfoil profiles.

A paper on the theory of arbitrary biplane wing sections in two-dimensional potential flow has been completed and is in process of publication. The theory may be regarded as a natural generalization of the method of Theodorsen in the treatment of the arbitrary single airfoil. (See Technical Report No. 411 and Technical Report No. 452.) The analysis is general and includes the effects of the following arbitrary parameters: Gap-chord ratio, stagger, chord ratio, decalage, and profile shapes. The individual velocity and pressure distribution on each wing of the biplane combination may be completely determined for any angle of attack. A method has also been outlined by which certain related families of biplane arrangements may be systematically produced in an artificial or indirect manner, for which the potential-flow characteristics are more readily derived. The numerical procedure has been carried through for a biplane arrangement of the N. A. C. A. 4412 airfoil, and a comparison made with the monoplane case.

#### THEORY OF AIRPLANE FLUTTER

The theoretical investigation reported in Technical Report No. 496 has been further extended to include the effect of damping. This work has not yet been published. It may be stated, in general, that friction has a beneficial effect or that the flutter is delayed when friction is present.

#### VIBRATION RESEARCH

The investigation of airplane vibration has been confined to the study of the cause of propeller failure. Close cooperation has been maintained both with the military branches and the industry. The purpose of this investigation is to produce rational design data on propellers and crankshafts, taking into account the complete vibration characteristics of the combination. Possibly the most distinct contribution by the Committee during the past year is the development of a method for determining the critical propeller frequencies of a revolving propeller. This method has been described in Technical Note No. 516, and is based on the use of a model propeller. A study of the effect of the mounting of the propeller on the hub, as compared with results obtained with the propeller suspended free in a sling, is also being conducted. The equipment described in last year's report has been further improved.

#### WIND-TUNNEL CORRECTIONS

The investigation of turbulence in the various wind tunnels of the Committee by drag and pressure measurements on spheres mentioned in the 1934 annual re-

port has been completed. In addition to the tests in wind tunnels, similar measurements were made in flight by suspending a sphere below an autogiro and in the practically motionless air of the N. A. C. A. tank by mounting the sphere on a spar ahead of the towing carriage. The results obtained in the tank agree closely with those obtained in flight, indicating that the atmosphere may be regarded as nonturbulent insofar as turbulence affects the boundary layer on airfoils of normal size.

Through a correlation of scale-effect measurements on airfoils in the full-scale and variable-density wind tunnels and the above-mentioned measurements on spheres, a tentative method of correcting the maximum lift coefficients of most airfoils for the effect of turbulence has been developed. This method, explained in Technical Report No. 530, involves the use of a "turbulence factor." If the actual Reynolds Number of a test on an airfoil in a certain tunnel is multiplied by the turbulence factor for that tunnel, the resulting "effective Reynolds Number" is that at which the measured maximum lift coefficient would occur in a nonturbulent air stream corresponding to flight.

In connection with the testing of airplanes in the full-scale wind tunnel difficulty has been experienced in accurately measuring the pitching moments with power on. It appears that with the airplane mounted in the tunnel the propeller slipstream may introduce a downwash effect at the tail which does not exist in flight. An investigation has been started to determine the nature and magnitude of this effect and, if possible, to arrive at a suitable correction.

#### ROTATING-WING AIRCRAFT

Considerable work on rotating wings and on rotating-wing aircraft has been accomplished during the past year. This research is being carried forward because of the marked advantages possessed by the rotating wing in comparison with the fixed wing in respect to safe, controllable flight at low speeds.

The published results of an investigation of a full-scale autogiro rotor in the full-scale wind tunnel (Technical Report No. 515) demonstrate the influence of blade pitch setting and rotor speed upon rotor characteristics. These data are now being used to check the validity of revisions to the strip analysis of the autogiro rotor.

The influence of change in the incidence of the fixed wing of an autogiro upon the load division and rotor speed has been determined in flight and the information published as Technical Report No. 523. The data have been presented so as to assist in the calculation of the wing incidence required for any load division; in addition, it has been shown that the inter-

ference effect of the wing upon the rotor is so small as to be negligible.

An investigation in flight on a direct-control type of autogiro employing a cantilever three-blade rotor has been made for the purpose of studying the rotor vibrations and the flapping and twist of the rotor blades. The results of this investigation will be incorporated in a report.

A report is now being prepared giving the results of a study of a series of autogiro models of 10-foot diameter in the propeller-research tunnel. The influences of changes in the rotor-blade airfoil section and in the blade plan form were studied; the results showed that it was disadvantageous to increase the airfoil section thickness from 12 percent to 18 percent and that the reduction of blade chord near the rotor hub reduced the lift-drag ratio of the rotor. Anomalies in the results indicated that the blades twisted during test, and indicated the necessity of investigating the influence of blade twist in order to isolate the influence of individual factors.

An experimental investigation of autogiro take-off, in which the kinetic energy of the rotor is employed to obtain an initially vertical flight path, has been started. The effects of blade pitch setting, initial rotor speed, and disk loading upon the height of free rise are being studied.

The results of an investigation in the propeller-research tunnel on a 10-foot-diameter gyroplane rotor have been published in Technical Report No. 536. Data that show the influence of blade pitch setting, solidity, and feathering angle upon the rotor characteristics have been obtained; the effect of feathering angle upon the control moments available was also studied.

#### AIRSHIPS

At the request of the Bureau of Yards and Docks, Navy Department, the wind pressures on a 1/40-scale model of the Lakehurst airship hangar were determined in the full-scale wind tunnel with the hangar mounted on a ground board and yawed 0°, 30°, 60°, and 90° to the wind. A screen was employed in the entrance cone of the tunnel to produce a wind gradient comparable with that previously measured in the vicinity of the landing space at Langley Field. In addition to the wind pressures on the hangar, a survey of the air velocity in its wake and a general study of the air flow about the hangar by means of smoke-flow photographs were made.

In order to determine the forces acting on an airship during handling while in proximity to the ground, an investigation was made in the full-scale wind tunnel on a 1/40-scale model of the U. S. airship *Akron* in which the lift, the drag, the cross-wind forces, and

the moments about the three axes were measured with the model at four different heights above a ground board and at each height yawed 0°, 30°, 60°, 90°, 150°, and 180° to the wind. In addition to the force measurements, photographs of smoke flow were made for each condition of yaw at one height. The wind gradient that was produced for the investigation of the wind pressures on a hangar was used.

Work on full-size airships during the past year has consisted chiefly in rendering assistance to the Army Air Corps and Bureau of Aeronautics of the Navy from time to time as requested. Instruments were installed on the Army TC-13 airship to record the tension developed in flight on certain fin brace wires to help explain structural failures of the fins encountered several times in flight. A multiple manometer has been installed in the U. S. airship *Los Angeles* for the purpose of determining the air loads due to winds with the airship at the mast. An accelerometer for airship use was designed and constructed and is being used in the mooring-out tests of the *Los Angeles*. In order to assist the Air Corps in determining the performance of airships a memorandum describing the procedure to be followed in making accurate measurements of air speed and rate of climb was prepared.

#### FIELD OF VIEW

The investigation of the field of view from pilots' cockpits has been continued throughout the year. A description of the method and apparatus employed and the type of chart developed has been published in Technical Report No. 514. The collection of charts for various airplanes has been extended to include, in particular, several new types of airplanes for the Bureau of Aeronautics, which now includes field-of-view charts for each airplane in its acceptance-test reports.

#### AIRPLANE RANGE

In view of considerable interest in the design of long-range airplanes, a rather complete analysis has been made of the factors involved and their relative importance in securing long range. A report is in preparation giving the results of this study. In it are discussed the essential features of airplanes designed for long range and reasonable compromises that may be made in the interest of utility.

#### MISCELLANEOUS SERVICES TO OTHER GOVERNMENT ESTABLISHMENTS

**Flotation-Gear Actuators.**—At the request of the Bureau of Aeronautics, Navy Department, the Committee investigated the pressures developed in flight by tubes which were mounted in various parts of the airplane and which, upon submersion, automatically actuated

the flotation gear. The purpose of the measurements was to determine whether there was any possibility that the positive pressures developed in flight would be sufficient to release the flotation gear, and whether the negative pressures would be of sufficient magnitude to damage the mechanism.

**Camera Shield on Bellanca Monoplane.**—The Committee conducted a brief investigation for the United States Coast and Geodetic Survey of the effectiveness of screens intended to protect in flight a new type of multiple-lens aerial camera from aerodynamic forces and from oil or dirt from the engine. It was necessary that the camera protrude several inches below the floor of the airplane fuselage and that the screen be several feet from the camera in order to avoid obstructing the camera field. A simple flat plate set normal to the air stream was first tried and was found to be unsatisfactory, because of the erratic flow condition behind it, which was eliminated by opening several narrow longitudinal slots in the plate to permit the passage of a limited quantity of air. An apparently satisfactory screen was thus obtained.

**Improvement of the Characteristics of the XFT-1 Airplane.**—At the request of the Bureau of Aeronautics, Navy Department, tests were made in the full-scale wind tunnel to improve the lift and drag characteristics of the XFT-1 single-seater fighter. Modifications of the N. A. C. A. engine cowling and the landing gear were made to reduce the drag, and the ailerons were drooped to increase the lift. By an extension of the lower part of the cowling back over the leading edge of the wing, the velocity of the air leaving the cowling slot was made to approach more nearly that of the air over the wing where the two streams joined. This arrangement reduced the drag coefficient of the airplane for the high-speed condition from 0.0453 to 0.0439. Compressing the landing gear 7.5 inches further reduced the drag coefficient by 0.0013. These two major changes, together with several minor ones, reduced the drag coefficient of the complete airplane to 0.0387, which should permit an increase in speed of 12.5 miles per hour for the same power.

Efforts to increase the maximum lift were less effective. Drooping the ailerons 15° increased the maximum lift coefficient only from 1.57 to 1.65; whereas the extension of the engine cowling, made to reduce the drag, increased the maximum lift coefficient from 1.57 to 1.64.

#### NATIONAL BUREAU OF STANDARDS

##### WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

**Apparatus for Measuring Turbulence.**—A simple apparatus utilizing the diffusion of heat downstream from a heated wire has been developed as a turbulence indicator. In principle the apparatus depends on the diffusing action of turbulence which causes the heated wake back of the wire to widen in proportion to the amount of turbulence present in the stream. From measurements of the width at a fixed distance back of the wire, it was found that the width depended only on the ratio of the root mean square of the speed fluctuations to the average speed, a quantity usually termed "percentage turbulence." The width of the wake is therefore taken as a measure of percentage turbulence. Unlike the critical Reynolds Number of spheres, mentioned in last year's report, the indication does not depend on the scale or eddy size of the turbulence, unless the eddy size is much smaller than that ordinarily found or the width of the wake is measured at great distance from the wire. This work has been published in Technical Report No. 524.

Mention was made in last year's report of the so-called "pressure sphere" as a simplification in the use of spheres for measuring turbulence in wind tunnels. Attention was directed to the fact that the critical Reynolds Number was not a function of the percentage turbulence alone, but also depended on the ratio of the size of the sphere to the size of the screen used to produce the turbulence. This has been taken as an indication that the size of the eddies as well as the magnitude of the speed fluctuations is an important factor in determining the effect of turbulence on boundary layers. The results are being analyzed in the light of recent theories, and preparation of a report is in progress.

**The Measurement of Average Eddy Size in Turbulent Air Flow.**—Both the work on diffusion of heat and that on the pressure sphere indicated the need for determining some length characteristic of the turbulence. In the earlier work on the pressure spheres, it was assumed that this length was proportional to some linear dimension of the object (in the present case, screen or honeycomb) producing the turbulence; but this procedure is uncertain, and at best gives no means of comparing results when the turbulence is produced by screens or honeycombs of dissimilar shape.

Work is now in progress on the measurement of the correlation between turbulent speed fluctuations at two points separated by known distances transverse to the wind-tunnel stream. Two electrically heated wires, 0.016 millimeter in diameter and 5 millimeters long, are placed at the points in question and the sum or difference of their fluctuating voltage drops is impressed on a vacuum tube amplifier. With suitable compensation for the lag of the wires, the average square of the alternating current from the amplifier

may be used to compute the coefficient of correlation between the speed fluctuations at the two points. From curves of the distribution of correlation with distance, a length may be determined which may be used as a measure of the average eddy size. The way in which eddy size of the turbulence ties in with the magnitude of the speed fluctuations to produce effects on boundary layers is being investigated in connection with the critical Reynolds Number of spheres.

A new amplifier, operated from an alternating-current line, has been developed for use with hot wires in turbulence measurements.

**Flow in Boundary Layers.**—The study of a separating laminar boundary layer on an elliptic cylinder has been completed and the results published as Technical Report No. 527.

**The Effect of Turbulence on the Drag of Flat Plate.**—During some turbulence investigations, evidence appeared to the effect that the drag of a flat plate normal to the wind increased with the turbulence of the stream. Since such an effect could not be explained in the manner of other effects of turbulence, the question arose as to whether turbulence might not be affecting the differential pressure indicated by the pitot-static tube, from which the speed was determined. A systematic investigation was therefore conducted on the drag of a flat plate, the difference in pressure between the front and rear of a thin circular disk, the rate of rotation of a vane anemometer, and the pressure developed by a standard pitot-static tube for several conditions of turbulence. The results were interpreted to indicate that there is no appreciable effect of turbulence on the vane anemometer and standard pitot-static tube, but that there is a small effect on the drag of a flat plate and the pressure difference between the front and rear of a disk. A paper describing this work has been completed and will appear shortly as a technical report.

#### AERONAUTIC INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments was conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department, and included the investigations and the instrument development outlined below.

**Lubricants for Instrument Mechanisms.**—The investigation of lubricants for aircraft timepieces and other fine mechanisms has continued. The aim of the investigation is to discover or develop a lubricant which will be satisfactory over a temperature range of  $-35^{\circ}$  to  $+45^{\circ}$  C., and which will have a life of 3 years in the mechanism. Present efforts are directed toward the development of a synthetic lubricant.

**Reports on Aircraft Instruments.**—The altitude-pressure tables based on the United States standard atmos-

phere were extended from 50,000 to 80,000 feet and published as Technical Report No. 538.

An improved method of testing oxygen regulators was described in Technical Note No. 532.

Results of an investigation of characteristics of aircraft compasses have been submitted for publication as a technical report.

**Tests and Test Methods.**—An investigation of the performance of gyroscopic instruments has been continued. The testing of these instruments for the Bureau of Aeronautics, Navy Department, has necessitated the construction of a special vibration board mounted in a temperature chamber and the purchase of a roll, pitch, and yaw machine (Scorsby).

A primary standard mercurial barometer for calibrating secondary standards has been constructed. A mercury vapor pump and a McLeod gage, connected to the barometer, make it possible to both control and measure the degree of vacuum in the space above the mercury. The instrument has an over-all accuracy of  $\pm 0.05$  millimeter of mercury.

Apparatus for testing aerometeorographs has been partially completed. Means are provided for subjecting the instruments to various combinations of pressure, humidity, and temperature.

**New Instruments.**—Instruments designed and constructed for the Bureau of Aeronautics, Navy Department, include: An improved carbon monoxide indicator and equipment for testing this instrument in the field; several experimental models of combination oxygen breathing mask and radio microphone; a maximum air-speed recorder with a range of 500 miles per hour; an improved fuel flow meter.

#### SUBCOMMITTEE ON AIRSHIPS

The Subcommittee on Airships formulates and recommends programs of airship investigations for conduct at the Langley Memorial Aeronautical Laboratory, and maintains close contact with the work in progress.

During the past year an investigation has been conducted to obtain information on the forces acting on an airship during ground handling, by means of tests in the full-scale wind tunnel on a large airship model at various heights above a ground board and at various angles of yaw with reference to the wind. The study of the theory of potential flow has been extended to the curvilinear motion of bodies of revolution, thus presenting information applicable to airships in flight.

An investigation to determine whether a sufficient amount of hydrogen could be efficiently burned in a compression-ignition engine to compensate for the increase of lift of an airship due to the consumption of

the fuel oil has been completed, and the results have been published as Technical Report No. 535.

At the request of the Bureau of Aeronautics of the Navy, the Committee is conducting, for the information of the special airship subcommittee appointed by the Science Advisory Board, a study of the effect of aspect ratio on the pressure distribution on airship fins. In addition, the Committee has designed and constructed for the Bureau of Aeronautics a special accelerometer for airship use.

Other airship projects on the Committee's research program at the present time include a study in the propeller-research tunnel of boundary-layer control for airships and an investigation of the effect of bow elevators on the resistance and controllability in pitch of an airship model.

#### SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

During the past year the Subcommittee on Meteorological Problems has given consideration to a number of questions relating to atmospheric conditions which are of particular importance in connection with aircraft design and operation.

The problems of ice formation and fog and fog dispersal have received attention from the subcommittee, but at the present time these problems are being approached chiefly as questions of design or operation rather than as problems to be solved through meteorological or aerological investigations.

**Investigation of Wind Gustiness.**—During the past few years an investigation of wind gustiness has been conducted by the Daniel Guggenheim Airship Institute at Akron, Ohio, with the cooperation of the Weather Bureau and the Bureau of Aeronautics of the Navy.

From an examination of the data collected in this investigation, it appears that the records are composed of rather fast fluctuations in velocity superimposed on much slower periods. Measurements have been made of the temperature differences at various times of the day between the top of the airship dock at Akron and the ground, and a formula has been developed to indicate in a general way the measure of the vertical velocity gradient of the gusts.

The program for this investigation includes the simultaneous measurement of the velocity gradient, temperature gradient, and slow-period fluctuations, and provides for obtaining data by means of balloons.

In the investigation of atmospheric gustiness the development of suitable instruments for obtaining records of air movements is of considerable importance, and a thorough study of the rotating-cup anemometer for such investigations has been made by Dr. Charles F. Marvin, formerly Chief of the Weather Bureau.

**Gust Conditions in Relation to Airplane Accelerations.**—An extensive study is being made by the Langley Memorial Aeronautical Laboratory of the accelerations experienced by transport airplanes in cross-country flying. For this study statistical data are being collected on a number of airplanes in regular transport operation. The object of this investigation is to obtain information as to the loads imposed on airplane structures as a result of operation in rough air. An attempt is being made to establish a relation between the atmospheric roughness, and significant weather or topographical conditions or both.

An investigation is also being undertaken by the Langley Memorial Aeronautical Laboratory to obtain information as to the variations of gust intensity with altitude, by means of frequent flights to altitudes of 17,000 to 20,000 feet in an airplane equipped with instruments to record air speed, accelerations, altitude, and humidity.

**Measurement of Gustiness and Wind Gradient Near the Ground.**—Simultaneous measurements have been made at Langley Field of the direction and magnitude of the wind at various heights above the ground up to 51 feet, by photographing with a motion-picture camera the positions of specially devised indicators at each of the vertical stations. This investigation was undertaken to determine the feasibility of making glide landings in gusty air.

The results of the wind measurements indicate an average increase in velocity with height. Maximum variations in the horizontal components of wind velocity were found to be of the order of  $\pm 4$  miles per hour without perceptible dependence on the average velocity or height, while maximum variations in vertical components were of the same order at the higher elevations, decreasing with height but with no perceptible dependence on wind velocity. Unchecked glide landings in gusty air with the conventional airplane were found to be unduly hazardous.

The results of this investigation have been published as Technical Report No. 489.

#### SUBCOMMITTEE ON SEAPLANES

The Subcommittee on Seaplanes was organized for the purpose of providing special consideration for research problems relating to seaplane design, and the research work conducted in the N. A. C. A. tank is under its direction.

The subcommittee held its first meeting at the Langley Memorial Aeronautical Laboratory on September 6, 1935, at which a general survey was made of the results obtained in the researches in the tank and the investigations at present under way. The future program of research and possible methods of adding to the value of the data obtained in the tank were dis-

cussed. In connection with the meeting, an inspection was made of the facilities of the tank and methods of making tests and of the models used. Motion pictures of the spray and wake characteristics of several models of floats and hulls were exhibited and a demonstration was made of the towing of a model through the water.

A statement of the research under way in the tank during the past year is given below.

**Seaplanes.**—The definite promise of air transport across the Pacific by means of flying boats and the belief that, once the trans-Pacific service is established, trans-Atlantic service will be developed very rapidly has led to a general increase in the interest in seaplanes and flying boats. The development of very large flying boats, of gross loads of 50 to 150 tons, is discussed with confidence. It also appears that private owners have become more interested in seaplanes as such, while new and larger amphibians are already under test or are being designed.

A recent development is the appreciation by pilots of the importance of holding the trim of a seaplane that is taking off to the best angles, i. e., the angles that give the least resistance. The N. A. C. A. trim-angle indicator described in Technical Note No. 486 has been successfully used by test pilots and improved take-off performances are reported to result from its use. An improved form of the instrument is now being designed.

Among the advantages derived from the great length of the N. A. C. A. tank is the ability to obtain several sets of readings in the course of a single run of the towing carriage. In order to use this advantage to the full, it was necessary to devise wave suppressors that would very quickly reduce the waves produced by a model to magnitudes that would not affect the next run. The wave suppressors now in use are described in Technical Note No. 513. They are so effective that test runs may safely be made in immediate succession and all the data for a general test of a model can easily be obtained in 2 days of operation.

The design of a model-cutting machine for use in making both wax and wooden models has progressed to the point where detailed plans have been started. This machine is designed to cut water lines, buttock lines, and transverse sections on the block from which the model is being made and should produce a substantial reduction in the time required to make a model, as well as in its cost.

Further experiment with wax as a material for models is being postponed until the model-cutting machine is available.

For years it has been the general practice in naval tanks to make all observations and to take all records

while the model is at constant speed. This method is entirely satisfactory for ship models because the main interest is in economy at constant speeds and also because, as a result of the large inertia of the ship, the speed changes relatively slowly while the weight on the water changes not at all. In the case of seaplanes, however, accelerations are high, the speed changes rapidly, and the weight on the water also changes rapidly. It is an attractive possibility that for the many constant-speed runs that are made at present there might be substituted a very few runs, or possibly a single run, in which the speed is accelerated from zero to a maximum and in which all the information desired could be obtained. The momentary values from such tests have so far shown poor agreement with those from constant-speed tests. The discrepancies are believed to be caused, in part at least, by the greater energy required to change from one type of flow pattern at one speed to another at a slightly higher speed as compared with the energy required to maintain either flow pattern.

Although the development of this type of testing is going very slowly, it has been found that observation of the continuous variations in the spray patterns is frequently more informative than observation of a succession of spray patterns at constant speeds. As a result of this observation motion-picture records of the spray during runs that were continuously accelerated from rest to get-away have been made and found to be of great value to student and designer. This process has been extended to dropping the model into the water while decelerating, thus simulating a landing. The two sets of pictures are not claimed to be accurate reproductions of the spray of the full-size seaplanes, but they do give more information than can be obtained from the usual constant-speed runs.

In the course of the take-off or the landing run of a seaplane there sometimes appears a combination of vertical and angular motions that is aptly termed "porpoising." This complex phenomenon appears to be the combined result of hydrodynamic, inertial, and aerodynamic forces although the hydrodynamic and the inertial forces seem to be the more influential. The tendency to porpoise sometimes appears in tests of models and usually is considered an indication that the actual machine will have the same tendency. A special towing rig has been constructed and a special light-weight model that may be ballasted to have the proper mathematical ratios of mass and moment of inertia to the full size is now available. This equipment is expected to make it possible to study the causes of porpoising and it is hoped to obtain information that may lead to a cure in specific instances.

**Effect of Variations in Dimensions and Form of Hull on the Take-off of Flying Boats.**—Improvement in the water

performance of flying boats has remained the principal object of the work of the N. A. C. A. tank during the past year. The effect of longitudinal flutes on the bottom, a construction that has been thought to have several advantages, was investigated for the Bureau of Aeronautics, Navy Department, on a model supplied by the Bureau (N. A. C. A. model 19). As received, the model had two longitudinal flutes on each side of the keel on both forebody and afterbody. The model was tested as received and then the flutes were replaced by the more conventional form on first the afterbody and then the forebody. When compared with the performance of an equivalent hull of conventional form, such as that of the PN-8, the performance of the original or modified model 19 was definitely poorer. The work with this model is described in Technical Note No. 522.

It is not enough that a seaplane float or hull have a good water performance; the form of the hull must be such as not to produce excessive resistance while in the air. Accordingly, it is part of the program on the improvement of the form of hulls and floats to determine the air drag of the various models that are tested in the N. A. C. A. tank and, in newer models, to try to combine low air drag with good water performance. A first group of 11 models have been tested in the N. A. C. A. 20-foot wind tunnel and the results are given in Technical Note No. 525.

The forms of hulls derived at the tank from tests of the series of related forms and exemplified in model 11-A, tests of which were reported in Technical Note No. 491, have been characterized by relatively simple forms of the bottom, usually with relatively straight cross sections and without flare or downward curvature at the chines. It was suggested that the form of model 11-A might be modified by the addition of a flare at the chine with a reduction in the spray and in the resistance. A new forebody was constructed incorporating a flare that increased the step forward in a manner that was believed to offer the most promise. When tested with the original afterbody form of model 11-A, it was found that although the spray had been reduced the resistance had been increased, as had also the trimming moments. The tests of this model (N. A. C. A. 11-G) are described in Technical Note No. 531.

## REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

For the consideration of the details of the program of the investigation of gaseous combustion, which had been approved to be conducted for the National Advisory Committee for Aeronautics by the National Bureau of Standards, a special conference was held at



the Committee's headquarters on August 7, 1935, and was attended by representatives of the National Bureau of Standards, the Bureau of Mines, and the Langley Memorial Aeronautical Laboratory. As a result of the conference the relation of the proposed program to other investigations being undertaken on the subject was clarified, the importance of the problem was emphasized, and it was agreed that interesting and valuable results would be obtained by the proposed method of research.

In order to remove difficulties and inconsistencies in the literature of the subject, a nomenclature for use in combustion research was agreed upon at the conference and this nomenclature has since been officially adopted by the National Advisory Committee for Aeronautics.

#### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

##### SPARK-IGNITION ENGINES

**Increase in Engine Power.**—The demand for higher speeds of military and commercial aircraft has accelerated the development of higher-powered aircraft engines. An increase in engine power has been obtained by improvements in cylinder design and by the use of gasolines having better antidetonating qualities. There are now available radial air-cooled engines rated at approximately 1,000 horsepower.

**Improvement in fuel quality.**—An improvement in the antidetonating quality of gasolines permits engine operation at higher compression ratios and increased manifold pressures. An investigation is in progress to obtain comparative data on the maximum engine performance that can be obtained with gasolines having a range of octane numbers, as determined by the C. F. R. motor method, from 87 to 100. The maximum compression ratio with atmospheric manifold pressure and the maximum boost pressure at a given compression ratio at which the gasolines can be used without detonation are being determined in a single-cylinder variable-compression liquid-cooled engine having a displacement of 113 cubic inches and operating at a speed of 2,500 revolutions per minute. The fuel giving the maximum performance will also be investigated in several single-cylinder air-cooled engines. The effect on the engine performance of inlet-air temperature, spark advance, and air-fuel ratio will be included in the investigation.

**Fuel injection.**—The substitution of a fuel-injection system for the carburetor on aircraft engines results in reliable engine operation at all attitudes of the airplane, in increased engine power, in more uniform fuel distribution, and in the elimination of the danger of ice formation in the engine. At present there are under development two types of fuel-injection systems. In

one type, the fuel is injected into the manifold close to the engine cylinder and in the other the fuel is injected into the engine cylinder. With injection into the cylinder a substantial improvement in power output can be efficiently obtained by using a large valve overlap and a slight boost pressure to scavenge the clearance volume of the engine. An investigation is in progress to determine the comparative engine performance obtainable with a high-speed single-cylinder air-cooled engine operating with a carburetor and with fuel injection into the manifold and into the cylinder.

**Supercharger intercooler.**—The demand for additional engine power at altitudes has resulted in the development of multistage and multispeed geared centrifugal superchargers. Because of the higher critical altitudes at which supercharged engines are operated, it has become necessary to use intercoolers to cool the compressed air, or charge, before delivering it into the engine. An investigation is in progress to determine possible methods of increasing the cooling taking place in the intercoolers and at the same time reducing the drag of the intercoolers. A wind-tunnel investigation is being conducted to determine the heat transfer and pressure drop through a new form of intercooler that should have relatively low drag.

**Reduction in Fuel Consumption.**—Distribution in multi-cylinder engines.—Since the weight of fuel required in a long-range airplane is approximately one-half the useful load, any reduction in fuel consumption is reflected either in increased useful load or in increased range. The distribution of the fuel between the various cylinders of a 9-cylinder radial engine operating over a wide range of brake mean effective pressures, engine speeds, and specific fuel consumptions is being studied by complete analysis of the exhaust gases from the individual engine cylinders. The work up to the present time has been limited to the variation in the constituents of the exhaust gases and in the air-fuel ratio, and the determination of the equivalent fuel wasted in the different cylinders. The data obtained on a 500-horsepower single-row radial engine indicate that the air-fuel ratio is considerably higher in the lower cylinders than in the upper ones.

**Exhaust-gas analysis.**—The use on airplanes of controllable propellers has necessitated the development of equipment that will indicate at all times the air-fuel ratio at which the engine is being operated. The most reliable method of determining the air-fuel ratio is the analysis of the engine exhaust gases. The relationships between the various constituents of the exhaust gases from four single-cylinder liquid-cooled test engines and one 9-cylinder radial air-cooled engine have been determined. The results of this investigation show that a definite relation exists among the constituents of the exhaust gases. Computations of



the air-fuel ratio and combustion efficiency from the exhaust-gas analysis show that they have a definite relation to each other and to the constituents. The relations found do not seem to have any relation to the engine operating conditions or performance. A report of this work is being prepared for publication.

**Fuel-injection systems.**—The results of an investigation to determine the distribution and regularity of injection from a 6-cylinder cam-operated fuel-injection pump have been published in Technical Report No. 533.

The research on fuel-injection pumps has been continued on a spring-actuated fuel-injection pump designed to have a rate of fuel discharge independent of the speed of rotation of the pump. The injection-valve chattering at low pump speeds, which is characteristic of the direct cam-actuated pump, is entirely absent with the spring-actuated pump. The rates of fuel discharge were found to be independent of the speed at which the pump was operated, and the pump injected the full fuel charge on the first stroke even at hand-cranking speeds. This last fact should be of particular advantage in starting, where good atomization of the fuel charge is very desirable. The rates of injection were found to vary with changes in the length and diameter of the injection tube, injection-valve opening pressure, and diameter of the discharge orifice. Up to the point of cut-off the rates of injection were independent of the fuel quantity discharged.

#### COMPRESSION-IGNITION ENGINES

**Combustion Research.**—Combustion characteristics of fuel sprays.—The N. A. C. A. combustion apparatus in conjunction with the special high-speed motion-picture camera has been used extensively during the past year. With the apparatus operating as a compression-ignition engine, an investigation has been made to determine the effect of air-fuel ratio, nozzle design, and air flow on combustion. The results of the investigation of air-fuel ratio indicate that in a combustion chamber in which the air is quiescent, or nearly so, the fuel charge is very definitely stratified at high air-fuel ratios. The start of burning relative to the fuel sprays was not affected by the air-fuel ratio nor was the rate of flame spread greatly affected by the ratio. At the higher ratios the rate of diffusion of the gases in the combustion chamber was relatively slow. Technical Report No. 525 presents the results of this investigation.

**Distribution of fuel within the combustion chamber.**—The attainment of a high specific power output per unit of displacement in the compression-ignition engine is dependent upon improvements in the distribution of the fuel sprays within the engine cylinder. The most effective method of obtaining distribution of the fuel in a vertical-disk form of combustion

chamber is to use a combination of multiple fuel sprays and suitable air flow. The N. A. C. A. combustion apparatus has been used to study the effect of air flow on fuel-spray distribution.

By the use of the schlieren optical system and a high-speed camera, motion pictures were taken of the air movement within the vertical-disk form of combustion chamber, a displacer piston being used to produce the air flow. Two important conclusions were reached from this investigation. First, the air flow actually existing in the engine may be very different from that estimated from the engine design because of the combined effect of the air movement produced during the air-induction period and that produced during the end of the compression stroke. Second, the fuel spray from a single round-hole orifice is not destroyed by the movement of the hot air. The air will sweep the spray envelope from the spray and will deflect the spray core, but the chances of completely destroying the core during the injection period are slight. The investigation indicates that with multi-orifice nozzles the combined effects of the sprays tend to destroy the air movement so that the effect on the sprays is less than would have been the case with nozzles having a single round-hole orifice. The results of this investigation are being prepared for publication.

**Distribution of fuel within the spray.**—A comparison of fuel sprays from several types of injection nozzles is presented in Technical Report No. 520.

The investigation to determine the distribution of the fuel within the fuel spray has been completed. Single-orifice, multiorifice, slit orifice, annular orifice, impinging-jet, pintle, lip, and centrifugal nozzles have been studied. The method consisted of spraying the fuel into a chamber containing compressed air and collecting the air-fuel mixture from different parts of the chamber by means of a sampling tube 0.040 inch in diameter. Tests were also made in which the fuel was sprayed against a series of concentric cups so that quantitative as well as qualitative data might be obtained. In this investigation sprays from the impinging jet and slit-orifice nozzles had the best distribution and the sprays from the single-round-hole orifices had the worst. In air at a density of 14 atmospheres the distribution of the fuel from the pintle nozzle was only slightly better than that from the single round-hole orifice but as the density was reduced the distribution with the pintle nozzle improved while that with the single round-hole orifice became worse.

**Vaporization of fuel sprays.**—A constant-volume bomb has been used to investigate the rate of heat exchange from the air to the fuel spray during the ignition-lag period. For this purpose a special differential-pressure indicator was constructed to record the pressure

drop in the gas in the bomb from the heat absorbed by the incoming fuel. Gas pressures up to 200 pounds per square inch and gas temperatures up to 570° F. were used. It was found that the pressure of the gas in the bomb decreased as soon as fuel injection started and that the rate of pressure drop was greatest at the start of injection. There was surprisingly little difference with changes in gas composition (air, nitrogen, and carbon dioxide were used), with the quantity of fuel injected, or with injection-nozzle design. It was possible to estimate the amount of fuel actually vaporized during the first 0.002 second by saturating the gas with the fuel and then injecting a charge of fuel. It was found that appreciable vaporization does take place. The results indicate that the rate of heat transfer to the injected fuel is extremely rapid as soon as the fuel and hot gas come in contact and decrease as injection proceeds. The results of this investigation are being prepared for publication as a technical report.

**Reduction of ignition lag.**—A theoretical analysis of the combustion taking place in compression-ignition engines indicates that a substantial improvement in performance could be obtained by reducing the time interval between the injection and combustion of the fuel spray. A possible method of accomplishing this result is to preheat the fuel before injection into the engine cylinder. An investigation to determine the effects of preheating fuel oil to 750° F. on the performance of a compression-ignition engine having precombustion chambers has been completed and the results prepared for publication. It was found that the maximum cylinder pressure and the ignition lag were materially reduced, the engine performance and the thermal efficiency were slightly improved, and the exhaust showed less flame and smoke as the fuel temperature was increased.

**Integral Type of Combustion Chamber.**—Without air flow.—The performance of the integral combustion chamber without air flow has been shown to be definitely inferior to that of the same chamber with forced air flow generated by a displacer piston. No further work with the quiescent chamber is planned. A technical report is being prepared to complete this investigation.

**With air flow.**—The improvement in performance by generating a forced air flow in the integral-type combustion chamber by using a displacer piston has been determined and the information published in Technical Note No. 518. Additional work has been conducted to determine the optimum displacer height, the best spray distribution, and the effect on engine performance of high-temperature coolant and boosting. A net brake mean effective pressure of 160 pounds per square inch was developed with a boost pressure of 5 pounds per square inch.

The principal methods of increasing the power output of compression-ignition engines is to increase the engine speed and the mean effective pressure. The standard test speed of single-cylinder engines has been increased from 1,500 to 2,000 revolutions per minute and will be further increased to a maximum speed of 2,500 revolutions per minute. This change in speed should result in a substantial increase in the power output.

**Hydrogen as an auxiliary fuel for compression-ignition engines.**—The results published in Technical Report No. 535 show that hydrogen can be satisfactorily burned in a compression-ignition engine at all loads up to and including airship cruising loads at compression ratios of 13.4 and 15.6 in sufficient quantities to compensate for the increase in the lift of an airship due to the consumption of the fuel oil.

**Prechamber Type of Combustion Chamber.**—The investigation of the prechamber, or divided, combustion chamber has been completed. The proper shape of the cylinder clearance was determined, as well as the effect of the compression ratio and the boost pressure on the engine performance. Optimum engine performance requires that the cylinder clearance be limited to only the necessary mechanical clearance, with as much as possible of the clearance volume in the prechamber. Increase in compression ratio resulted in improved indicated performance but also increased the friction mean effective pressure. The optimum compression ratio was 15.5. Boosting improved the indicated engine performance at all loads and the net brake performance at high loads. Because the clearance volume of the prechamber head cannot be scavenged without mechanical complication, this type of combustion chamber is incapable of the high specific outputs attainable by other less restrictive types, notably the displacer-piston combustion chamber.

Technical Note No. 514, describing the effect of combustion-chamber shape on engine performance, has been published and a technical report summarizing all previous work is being prepared to conclude this investigation.

**Two-Stroke-Cycle Engine.**—The study of the exhaust, scavenging, and charging phases of the two-stroke-cycle compression-ignition engine has been continued. Two rotary valves were constructed and installed in the exhaust passages beyond the poppet exhaust valves to increase the range of control of the timing of the scavenging and the charging. The amount of air passing through the cylinder during the scavenging portion of the cycle was regulated, without affecting the initial stages of exhaust through the poppet valves, by varying the phasing of the rotary valves. The investigation with the rotary valves showed that the engine performance increased with increase in scaveng-

ing period and scavenging air flow up to a definite maximum, beyond which the performance decreased, indicating the existence of an optimum relationship between the times allotted for scavenging and charging the cylinder.

#### COWLING AND COOLING

**Finned Cylinders—Cooling properties.**—The power output of an air-cooled engine is limited by the quantity of waste heat that can be dissipated from the cylinder fins to the cooling air. The principal factors affecting the quantity of heat dissipated by the cylinder fins are the fin spacing and the air velocity between the fins. The previous investigation of the cooling of finned cylinders, described in Technical Report No. 511, showed the need for further information on more closely spaced fins. Data have been obtained for conditions in which the space between the fins was varied from 0.022 to 0.131 inch. The cylinders were tested in a wind tunnel with and without baffles, and were completely enclosed in a jacket, a blower supplying the cooling air. For each of the three conditions studied the highest heat-transfer coefficient based on the cylinder wall area was obtained with a fin space of approximately 0.046 inch. The results of this investigation are being prepared for publication.

**Air velocity between fins.**—A study was made to determine the air-flow characteristics around finned cylinders. The investigation included a smooth cylinder, a finned cylinder having several fin spacings and fin widths, and a cylinder with several types of baffles with the entrance and exit shapes varied. The air velocity around the cylinder and between the fins was measured with impact and static tubes made of stainless-steel tubing 0.015 inch in outside diameter. The results of these tests showed that flow characteristics around a cylinder are not so critically affected by changes in fin width as they are by changes in fin spacing. The design of the cylinder baffle based upon air-velocity measurements checks the baffle design determined from previous measurements of the heat transfer. A technical report presenting the results of this investigation has been prepared for publication.

**Engine Cooling—Cylinder-temperature correction.**—An investigation is being conducted to determine the effect of variation in cooling-air temperature on the cylinder temperatures of air-cooled engines. The results of this study will be of importance in reducing cylinder-temperature data to a standard air temperature, and will also serve as a basis for predicting engine cooling under various atmospheric conditions. Six cylinders representing current service-type engines are being studied. These cylinders are tested as single-cylinder engines, the cooling-air temperature being varied from

atmospheric to 250° F. above atmospheric. For each cylinder investigated, the increase in cylinder temperature with increase in cooling-air temperature has been found to be practically constant and to be independent of the brake mean effective pressure, the engine speed, and the weight velocity of the cooling air. With increase in carburetor-air temperature there is a small increase in cylinder temperature provided the engine speed, brake mean effective pressure, air-fuel ratio, and cooling-air temperature remain constant.

**N. A. C. A. engine cowlings.**—The investigation of the factors influencing the design of N. A. C. A. cowlings for radial air-cooled engines in order to obtain low drag and satisfactory engine cooling has been continued. The research is being conducted with a Pratt & Whitney R-1340 S1H1-G engine installed in a nacelle and mounted in the propeller-research tunnel. The distribution of temperature over the engine with 18 cowling combinations has been determined for a wide range of engine power and tunnel air speed. The effect on engine temperature of operating with a 3-blade controllable and a 3-blade adjustable propeller has been investigated. The mixture distribution of each cylinder has been determined for several engine powers and specific fuel consumptions by analysis of the exhaust gases from each cylinder. The analysis of the data obtained on drag and engine cooling indicates the need for further study of the cooling problem to determine the efficiency of this method of engine cooling.

**Blower cooling.**—The use of a blower to supply the cooling air for an air-cooled engine would insure positive engine cooling under all engine-operating conditions. An investigation has been undertaken to determine the quantity of air and pressure drop required for cooling a given design of radial engine. This investigation is being conducted on single-cylinder engines with the cooling air supplied by a blower to determine the quantity of air and pressure drop required for a range of power outputs and specific fuel consumptions. The results show that from 1 to 4 percent of the brake horsepower of the engine is required for adequate cooling with an assumed blower efficiency of 100 percent. The results of the investigation with cylinders having fine and coarse pitch fins are being prepared for publication.

**Cooling at altitude.**—An analysis is being made to determine the comparative cooling at altitudes and at sea level of supercharged air-cooled engines in a high-speed transport and a pursuit airplane. The estimated cooling is based on data obtained from wind-tunnel tests of a multicylinder engine mounted in a nacelle and from single-cylinder engine tests. The calculations indicate that, for an airplane equipped with a supercharger and a controllable propeller maintaining constant engine power, the cylinder tempera-

tures increase with altitude, and that the higher the temperatures at sea level the greater will be the increase with altitude.

#### INSTRUMENTS

**Engine Indicator.**—The Farnboro indicator and the technique of its use have been developed so that reproducible low-pressure cards can be obtained. The indicator has been used in the study of pressures existing in the inlet pipe, the cylinder, and the exhaust pipe of the 2- and 4-stroke-cycle test engines with variation in valve timing, pipe lengths, and inlet and exhaust time-areas.

**Fuel Flowmeter.**—An electrical type of indicating flowmeter has been developed for measuring high mass rates of flow of gasoline or other nonconducting fluids. The meter has been so designed that its indication is independent of temperature over a wide range and that it has no known vibrational or viscosity errors. The ratio of maximum to minimum rates of flow, measurable within 1 percent, is 10 or more, the values being approximately 60 to 600 pounds of gasoline an hour.

**Rate-of-Fuel-Injection Apparatus.** A complete analysis of the combustion process in the engine cylinder requires a knowledge of the instantaneous rates of fuel injection. An apparatus is being designed to enable a complete record to be rapidly obtained of the rate of fuel injection without removing the fuel pump from the engine.

#### NATIONAL BUREAU OF STANDARDS

**Phenomena of Combustion.**—Studies of the effects of water vapor and ratio of fuel to oxygen in exploding mixtures of carbon monoxide and oxygen are described in Technical Reports No. 531 and No. 532. An investigation of the effects of the inert gases argon and helium upon flame speed and expansion ratio in mixtures of carbon monoxide, oxygen, and water vapor was made by the constant-pressure or bubble method. For the particular gas mixtures used it was found that, with the possible exception of helium in very small amounts, (1) the addition of inert gas always produced decreased flame speed and expansion ratio, (2) like volumes of argon and helium have very different effects upon flame speed but practically the same effect upon expansion ratio, and (3) the difference in the effect of these two gases is independent of the ratio of fuel to oxygen. The results of this investigation are being prepared for publication as a technical report. The adoption by the Committee of a standard nomenclature on combustion research acceptable to the various workers in this field was proposed. An improved method of studying gaseous explosions in a spherical bomb of constant volume,

equipped with (a) means for photographing the spread of flame from a central ignition point and (b) several indicators of the balanced diaphragm type arranged to record the points at which predetermined pressures are reached, has been outlined.

**Combustion in the Engine Cylinder.**—A further report on flame movement and pressure development in an engine is being prepared for publication by the Committee.

The investigation of chemical changes taking place in the detonation zone by means of composite photographic records of absorption spectra has been continued for the Bureau of Aeronautics, Navy Department. A photo-elastic gage, designed to give continuous oscillograph records of pressure changes within the combustion chamber, is under construction. Methods of detecting the occurrence of detonation in service engines and evaluating knock intensity are being studied.

**Factors Affecting Volumetric Efficiency.**—An exact and generally applicable equation has been developed for the volumetric efficiency of engines with no valve overlap. The principal variables in this equation are the pressure  $P_R$  in the cylinder when the exhaust valve closes trapping the residual gases, the pressure  $P_I$  when the inlet valve closes on the fresh charge, and the net departure from adiabatic conditions during the induction period expressed as a temperature change  $\Delta T$  in the induced charge. Data collected during nearly 100 motoring runs at full throttle have been analyzed to show the effects of engine speed, entering-air temperature, and jacket-water temperature upon the volumetric efficiency and upon the three variables  $P_R$ ,  $P_I$ , and  $\Delta T$  in a single-cylinder engine.

**Ignition Research.**—The ignition laboratory has cooperated with the Bureau of Aeronautics, Navy Department, in the development of procurement specifications for magnetos and is engaged in testing the electrical performance characteristics of various magneto types.

An improved type of shielded spark plug has been developed and specifications for the procurement of such plugs have been prepared. Shielding is obtained by means of a metal cage made integral with the spark-plug shell. The design specified gives shielding equal to that provided by complete metallic enclosure. Protection against moisture and flashover is secured by means of an insulating sleeve which screws on the top terminal of the plug. This design reduces cable temperature both by dissipating heat and by reducing heat flow.

Pending the development of ignition cable which will stand considerably higher temperatures, precautions are sometimes necessary to prevent cable burning at the point where the cable is attached to the

conventional shielded spark plug. However, the temperature surveys made on new types of airplanes are not limited to ignition-system temperatures.

**Detonation Rating of Aviation Fuels.**—The comparative tests of aviation fuels in representative military and commercial aircraft engines, made by the National Bureau of Standards in cooperation with three engine companies, have been substantially completed. The Cooperative Fuel Research Committee which sponsored this investigation is expected to recommend no change in present laboratory methods of rating aviation fuels, pending an extension of the work to include fuels of high octane number. The Canadian National Research Council plans to compare the original set of test and reference fuels in a supercharged Jaguar engine. Technical iso-octane, iso-octane plus lead, and iso-octane blended with small percentages of a 20 octane number straight-run gasoline are proposed as standard reference fuels for use in full-scale engine tests of fuels in the range of high octane numbers.

**Aviation Oil Stability.**—An investigation of the stability of aircraft-engine lubricating oil has been undertaken in cooperation with the Bureau of Aeronautics, Navy Department. The object of the work is to develop a convenient laboratory test for oil stability that will reproduce the changes which take place in the oil during service. Two Hornet engines are being operated on a variety of commercial aviation oils and samples are removed periodically for analysis during each run. Several types of laboratory tests are being studied, all of which involve heating of the oil under oxidizing conditions. Evaporation loss is measured and analyses are made of the viscosity, sludge, acidity, and carbon residue.

**Investigation of Engine Cooling.**—A study of the cooling characteristics of an inverted in-line engine when installed in a pusher-type airplane, undertaken at the request of the Bureau of Air Commerce, has been completed. The various arrangements of cowlings and baffles used fall in two groups according to whether the cylinder heads were cooled by longitudinal or transverse air flow. In all cases the air flowed transversely across the cylinder barrels. In the first group, the arrangements were modifications of the type of cowlings and baffles ordinarily used with in-line engines, although special attention was given to the cylinder-head baffles. In the second group, the basic design consisted of a "high-pressure" chamber on one side of the engine with a "low-pressure" chamber on the other side. Usually an outlet opening, surrounded by a lip which the propeller just cleared, served to maintain some suction in the low-pressure chamber. A cowlings of this type, which has louvers for the incoming cooling air, is being tried on an experimental tailless airplane recently acquired by the Department of Commerce.

**Investigation of Exhaust Gas.**—A preliminary investigation was made at the request of the Bureau of Aeronautics, Navy Department, to ascertain what becomes of the lead when an aircraft engine is operated on gasoline treated with tetraethyl lead. A Wasp engine was operated under full-throttle and cruising conditions on aviation gasolines containing average and high concentrations of tetraethyl lead. The solids in the exhaust from a representative cylinder of the engine were collected with an efficient electrostatic precipitator during a 10-minute run under each test condition and were analyzed for lead, bromine, and sulphur. Both lead bromide and lead sulphate were detected microscopically but the total amount of lead found was insufficient to combine with all the bromine and sulphur. The lead recovered was, on the average, about 25 percent of the lead brought into the cylinder by the fuel, yet the lead retained in the engine at the conclusion of the tests was only approximately 5 percent of the total lead in all the fuel burned. This indicates that continuous runs of many hours' duration would be required to obtain a true lead balance and is in accord with earlier experiments on a small single-cylinder engine, in which the lead content of the exhaust was found to vary between 10 percent and 119 percent of the amount introduced as fuel.

**Automobile Engines for Airplane Use.**—At the request of the Bureau of Air Commerce, a popular V-type automobile engine which develops about 90 horsepower at 4,000 revolutions per minute but weighs more than 5 pounds per horsepower is being subjected to a 300-hour dynamometer endurance test at full throttle and rated speed. This is part of a program to determine the feasibility of producing reliable airplanes for the private flyer at moderate cost.

#### SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

For the purpose of encouraging and coordinating research on problems relating to improvements in aviation fuels and lubricants with a view to obtaining the maximum possible performance in aircraft engines, the National Advisory Committee for Aeronautics, at the recommendation of its Committee on Power Plants for Aircraft, established the Subcommittee on Aircraft Fuels and Lubricants.

Two meetings have been held by this subcommittee since its organization in May. The present needs in connection with the improvement of aviation fuels were summarized and discussed, and consideration was given to the present status of the development of lubricating oils for aircraft engines and the problems to be investigated.

Some of the principal problems considered by the subcommittee are outlined below.

**Determination of Antiknock Value of Fuels.**—Comparative data are being obtained on the performance of fuels of high octane number in service engines of the Army Air Corps and the Bureau of Aeronautics of the Navy, and on the laboratory tests of the fuels used. However, the information so far received gives no indication of the relative applicability to fuels of high octane number of the respective methods used by the two services for rating fuels as to their antiknock value. The method used by the Air Corps (Air Corps specification 3566) and the C. F. R. method used by the Bureau of Aeronautics give ratings which are in substantial agreement for fuels up to about 80 octane number. In the range above 80 octane number, most fuels, except aromatic blends, are rated higher by the Air Corps method than by the C. F. R. method, which is used by the industry as well as the Bureau of Aeronautics.

A study of this problem is being included in the program of investigation being conducted by the National Bureau of Standards for the Bureau of Aeronautics of the Navy.

**Lubricants for Aircraft Engines.**—At the National Bureau of Standards a program of investigation relating to the lubrication of aircraft engines is under way with the cooperation of the Air Corps and the Bureau of Aeronautics. Some of the specific problems included are the oiliness of aviation oils, oil stability, cylinder-wall and piston-ring wear, and the effect of oil acidity on bearings.

An investigation of the stability of compounded aviation oils, including the development of a test method for the stability of compounded oils which will be significant as regards engine performance, is being conducted by the National Bureau of Standards for the National Advisory Committee for Aeronautics, in accordance with a program outlined under the direction of the subcommittee.

## REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES AND MATERIALS

As a result of the reorganization of the Committee on Aircraft Structures and Materials and its subcommittees, and of the supplemental appropriation obtained by the National Advisory Committee for the present fiscal year, the activities of the Committee on Aircraft Structures and Materials and its subcommittees have been appreciably increased, both by the expansion of projects already under way and by the addition of new projects. The greater part of this increased activity is taking place at the National Bureau of Standards.

### SUBCOMMITTEE ON METALS USED IN AIRCRAFT

**Weathering of Aluminum-Alloy Sheet Materials.**—Supplementing a five-year series of weather-exposure tests, the results of which were published in Technical Note No. 490 of the National Advisory Committee for Aeronautics, a second series in which newly developed alloys were included was begun. This has progressed for three years at Washington and Coco Solo, and one year at Hampton Roads, where the initial specimens were lost during a hurricane.

Continuous exposure of this duration has shown that materials containing from 1 to 6 percent magnesium as the principal alloying constituent are very resistant to atmospheric corrosive attack. On the other hand, alloys of the duralumin type, containing up to 4 percent copper, proved relatively more susceptible to attack, especially in the marine localities. Coatings of pure aluminum forming an integral part of the sheet have afforded complete protection to specimens of the duralumin-type alloys to date. Systematic examination of specimens of sheet material of this kind, Alclad from the hull of the airship MC-2, have shown penetration of the aluminum protective skin in small areas after about six years. Deeply penetrating attack of the basis metal has not been observed, however, as yet.

The majority of the paint and varnish coatings applied to the oxide-treated surfaces of specimens showed initial evidences of failure during the second year. When applied to surfaces not oxide-treated, failure on a number of the coatings began in less than six months and was practically complete shortly thereafter.

Oxide coatings applied by anodic treatment have proved greatly superior to those obtained by chemical immersion methods; the latter exhibited evidences of failure in less than six months. Anodic coatings impregnated with chromic oxide after anodizing in chromic acid electrolyte have shown marked superiority over similar coatings not so treated.

Accompanying the outdoor weathering tests, laboratory tests have been carried out by the salt spray method, over 3,000 specimens having been tested. Some of the materials which are proving most satisfactory under weather conditions have successfully withstood ten months' continuous exposure to salt spray without breakdown.

**Weathering of Magnesium Alloys.**—The durability of magnesium-base alloys under service conditions is intimately related to their degree of corrosion resistance. The tests of a series of these alloys representative of several compositions in sheet form extending over a period of five years of continuous exposure to the

weather have been completed. A summarizing report for the use of interested Government agencies has been prepared. In general, chloride corrosion, such as is characteristic of marine exposure, is the most serious condition encountered. Failure under such condition is often the result of crevice corrosion. Under inland conditions the corrosion resistance of these materials is greatly superior.

Further weathering tests of present-day commercial alloys are under way, with special emphasis on the surface treatment of the metal prior to coating as well as the character of the applied coating. The tests are being conducted at Coco Solo, Canal Zone, representative of severely corrosive marine conditions, and at Washington, D. C., representative of mildly corrosive conditions. Unlike some of the light aluminum alloys, deeply penetrating intercrystalline corrosion resulting in brittleness of a sheet has not been observed in these alloys. The corrosive attack is confined to the surface and results in a gradual reduction in the thickness of a sheet.

**Surface Treatment of Magnesium Alloys.**—The adherence of any protective coating applied to magnesium alloy and, therefore, its effectiveness, depends in large measure on the character of the surface to which it is applied. Much study is being devoted to this subject and a rapid method for the surface treatment has been developed which, according to extended salt-spray corrosion tests, promises to be decidedly superior to methods now in use commercially for the surface treatment of magnesium.

**Protective Treatment of Aluminum—Anodic Oxidation.**—The value of anodic oxidation as a preliminary treatment of aluminum is now widely recognized. Because of operating difficulties encountered in obtaining good quality oxide film, a study was made at the request of the Bureau of Aeronautics of various bath conditions which may affect the character of the surface films. It was shown:

(a) Hexavalent chromium ( $\text{Cr}^{\text{VI}}$ ) is the effective agent in anodization,

(b) Aluminum taken into solution from the alloy treated is largely responsible for premature failure of chromic acid anodizing baths,

(c) Aluminum content of the solution may be kept low by addition of a substance containing trivalent chromium ( $\text{Cr}^{\text{III}}$ ),

(d) The pH of the bath which is a function of the free  $\text{Cr}^{\text{VI}}$  should be maintained within fairly close limits,

(e) A practical control chart, correlating the chemical analysis, the calculated free  $\text{Cr}^{\text{VI}}$ , and the pH of the bath with the operating conditions is being constructed.

**Aircraft Metals at Sub-Zero Temperatures.**—For aircraft, it is not sufficient merely to specify materials of construction of satisfactory properties as ordinarily determined at normal temperatures. The possible condition, especially of a deleterious nature, which may obtain while the structure is maintained for a time at various operating temperatures should be known. In line with this, the mechanical properties of the important metallic materials are being studied in cooperation with the Bureau of Aeronautics at a series of temperatures the lowest of which is below the lowest encountered in service. In general, low temperature serves to accentuate the deleterious effect of notches or similar surface imperfections on the properties of most of the materials.

**Propeller-Blade Materials.**—Of four aluminum-alloy propeller blades examined during the year, two had failed in service, one during a test flight of a new airplane, and the other during an engine test on a test-block. Both failed as the result of a fatigue fracture at the hub. The examination of two other blades was prompted by the belief by the maintenance personnel that the peculiar grain structure and marked contrast in grain size exhibited on the surfaces of the blade was an indication of defective material. No evidence that such was the case was found.

Numerous rotating-beam fatigue tests have been made on specimens machined from hollow welded-steel blades; some new, some used but without failure, and one blade that had failed in service as the result of fatigue. The endurance limit has been determined on specimens from the basis steel (S. A. E. 6130) where it was not affected by the welding operation; on specimens consisting mostly of weld metal; on specimens consisting partly of weld metal and partly of basis steel and containing defects detected by the magnetic-dust inspection method; and on specimens containing surface defects similar to those found on the blades, some of which are apparently unavoidable. Blades are now being plated with chromium by some makers to provide resistance to surface corrosion and abrasion, and fatigue tests to obtain information on the possible effect of the chromium coating on the fatigue limit of the steel are necessary. No important conclusions can as yet be stated on the basis of the results.

**Miscellaneous Aircraft Metals.**—Of the service failures of fittings of various kinds examined during the year, fatigue failures by far outnumber those resulting from improper material. "Stress raisers" such as may result from improper design features, from defects introduced by welding, etc., serve to localize the fatigue break.

Corrosion of fuel tanks and lines is evidently an important matter as evidenced by the failed materials ex-



amined. Salt-water corrosion appears to be the primary cause, but the severity and distribution of the corrosive attack seem to be influenced by the character of the deposit resulting from decomposition of the treated gasoline used. Improper heat treatment and insufficient surface protection are apparently of major importance in contributing to the failure of the high-strength aluminum-alloy parts.

#### SUBCOMMITTEE ON STRUCTURAL LOADS AND METHODS OF STRUCTURAL ANALYSIS

##### LANGLEY MEMORIAL AERONAUTICAL LABORATORY

**Applied Loads on Airplane Structures—Wing-load factors.**—The collection of statistical information on gust loads on the wings of transport airplanes has been continued during the past year. No loads greater than those previously obtained have been measured. The collection of such data is being extended to smaller cabin types of airplanes and to large flying boats intended for transoceanic operation.

As a result of interest in the possibilities of transport flying at high altitudes, plans are being made to incorporate aneroid elements in the instruments so that the measured loads may be evaluated as a function of altitude as well as of air speed.

In order to establish gust criteria for the design of light airplanes and of gliders, an investigation is planned to establish a correction of the sharp-edged gust formula for such cases. A preliminary analysis indicates that this formula should not be applied to airplanes having wing loadings much less than 10 pounds per square foot.

Acceleration measurements have been made on a number of racing airplanes in both simulated and actual races, and the results have been published in Technical Note No. 537. The values of acceleration measured ranged from 6.2 g to -1.2 g.

**Tail loads.**—A number of measurements of tail loads in rough air have been made. Although these measurements are not yet sufficiently complete to furnish a basis for general conclusions, they indicate that gust loads on tail surfaces may be appreciably higher than might be expected from the wing-load measurements. During flights that have been made in moderately rough air, unit loads on the vertical surfaces have generally been higher than those on the horizontal surfaces; but during one very rough flight immediately following the passage of a wind-shift line, the reverse was the case.

**Load Distribution—Wings without flaps.**—A study of theoretical and experimental span load curves for wings without flaps has been made to formulate a rational design procedure for the determination of the load distribution. The theoretical curves represent

well the experimental results below the stall, except for wings having a tip chord greater than half the root chord. For such cases empirical tip corrections have been derived. A report is being prepared on this subject.

A procedure has also been established for calculating the complete force and moment distribution on monoplanes and biplanes. In this procedure a force coefficient is treated as the independent variable, thus as far as possible eliminating the angle of attack; the forces are derived in terms of certain basic parameters of the airfoil sections, which are tabulated for a number of well-known and commonly used sections; and the forces are then progressively built up from simple combinations of certain basic forces and simple formulas involving the airfoil section parameters.

**Wings with flaps.**—Although the wing with flaps is not fundamentally different from the wing without flaps as far as force calculations below the stall are concerned, the almost unlimited variety of flap types and dimensions requires considerable analysis to establish the section characteristics of flapped airfoils and to determine the influence of the discontinuity of the wing form in cases involving partial-span flaps. These problems have been partly solved during the past year and the progress made indicates that a solution sufficiently complete for the purpose of structural analysis will soon be made. A report covering this subject is in preparation.

Investigations have been made on airfoils with flaps to obtain data applicable to the structural problem. These tests include force measurements in the 7- by 10-foot wind tunnel on the wing and flap of an N. A. C. A. 23012 airfoil with an N. A. C. A. 23012 external-airfoil flap, pressure-distribution measurements in the same wind tunnel on an airfoil with a flap and a tab, and flow studies in the smoke tunnel to determine the character of the flow in the vicinity of the tail surfaces of low- and mid-wing monoplanes equipped with double split flaps. In the smoke-tunnel investigation, it was found that with ordinary double split flaps pulsations of a character likely to cause severe buffeting of the tail surfaces occurred, but that it was possible, at least at the low scale of the model tests, to reduce the pulsations by the use of spanwise slots in the flap. Pressure-distribution measurements have also been made in flight to determine whether the pitching of the wing in accelerated-flight conditions might cause a change in the section characteristics. The effect was negligible.

**Unsymmetrical wing loads.**—A report is in preparation giving the results of a study of unsymmetrical wing loads that was undertaken to establish more rational design criteria. Thus far, the theoretical analysis of previous investigations of ailerons has been



extended to linearly tapered wings with several aspect ratios. It has been found possible to effect a fairly close agreement between the theoretical and experimental rolling moments for both the fixed and rolling conditions by introducing into the theoretical expression for the rolling moment an effective change in angle of attack obtained from an analysis of flap data.

**Compressibility effect.**—An investigation made at very low scale in the high-speed wind tunnel had indicated sufficient change in the pitching-moment coefficient at usual diving speeds to justify a consideration of the compressibility effect on the structural design of rapidly diving airplanes. Apparatus has been installed in an airplane for the purpose of verifying the wind-tunnel results under full-scale conditions, also to verify airfoil section data at lower speeds where the compressibility effect is negligible and to check certain wing-flutter criteria.

**Water pressures on seaplane hulls.**—The Committee has continued to cooperate with the Bureau of Aeronautics, Navy Department, in the measurement of maximum water pressures on various seaplanes during routine acceptance tests. Maximum pressures have been recorded on an amphibian flying boat, the RD-3; a single-float seaplane, the O3U-6; and a large flying boat, the XP3Y-1. Pressures as great as 50 pounds per square inch have been recorded.

At the same time the Committee has been developing a water-pressure recorder that will give a continuous record of pressure travel on waxed paper. An experimental instrument of this type has been tried in flight tests and a final design has now been completed.

**Structures.**—As a result of the analysis by Schwartz and Bogert of a strut with a single elastic support in the span (Technical Note No. 529), a deflection formula for single-span beams of constant section subjected to combined axial and transverse loads has been derived and presented in Technical Note No. 540. The formula may be considered general to the extent that it is applicable to a variety of cases heretofore requiring separate formulas for each case. The formula makes possible a general study of the effect of axial load on the spring constant of a beam and is therefore of special interest in jury-strut problems.

#### NATIONAL BUREAU OF STANDARDS

**Inelastic Behavior of Duralumin and Alloy Steels in Tension and Compression.**—The study of the inelastic behavior of thin sheet materials in tension and compression has been continued. Compression tests by the pack method (briefly described in last year's report) have been successfully carried out on heat-treated chromium-molybdenum steel sheets as thin as 0.05 inch and stressed up to 185,000 pounds per square inch. This

is probably near the practical limit of sheet material for aircraft.

Results from previous tests of aluminum alloys by the pack method have been used in the study of the failure of wing beams. The beam tests correlated much more closely with the compression stress-strain curves than with the tension stress-strain curves.

**Fixation of Struts.**—Additional column tests of streamline tubing of duralumin, stainless steel, and normalized and heat-treated chromium-molybdenum steel have been made with both freely supported ends and elastically restrained ends. With these tests the experimental part of the investigation as far as has been planned has been completed.

Column formulas have been fitted to the test data for the four materials which were used.

A method has been developed for applying the results of these tests to the design of structures continuous at the joints. This method has been applied to the analysis of a fuselage which was tested statistically by the Bureau of Aeronautics of the Navy Department. The member which the analysis indicated as the weakest member was the one which actually failed in the test, whereas the conventional method of analysis predicted failure of a member which did not in fact fail.

A report covering the investigation has been prepared.

**Tubing under Combined Axial and Transverse Loads.**—The tests reported in Technical Note No. 307 showed considerable variation of modulus of rupture with varying test conditions. Pending a more thorough study of these variations the design charts given in the technical note were based upon a safe, conservative value for the modulus of rupture.

Examination of the test results has indicated the probability that with fuller knowledge of the effect of the different variables in the test conditions, somewhat higher values might be safe. For that reason a series of tests on the modulus of rupture of tubing is being started.

The previous tests had indicated an apparent variation of the modulus of rupture with length of tube. For that reason tests were made in which equal and opposite terminal couples were applied to specimens of different lengths cut from the same tube. No differences in moduli of rupture were found which were as great as 3 percent, an amount to be expected from unavoidable variations in the material and cross section.

When subjected to bending moments the cross section of a circular tube flattens into an approximately elliptical shape, and the maximum bending moment which the tube can carry depends somewhat on the amount of this change of shape, which may be influenced by

the type of connection used in applying the lateral load.

If the section of the tube at the loading points (third points) is constrained to remain circular, the flattening can only occur in the free span between loads, and failure takes place at the middle of the specimen uninfluenced by local effects caused by the method of loading.

Preliminary tests have shown also that as long as the lateral load is applied by means of a member in tension, no practical type of connection will accentuate this change of shape, so that the moduli of rupture are not lowered by this type of loading. On the other hand, if the load is applied through a member in compression, the attachment to the tube may tend to accentuate flattening of the tube section and cause some reduction in the modulus of rupture; tests in which the lateral load was so applied gave somewhat lower values.

As the result of these preliminary tests, the main tests will be run with the load applied by means of the same fixtures used in the earlier part of the investigation, but greater attention will be given to the elimination of axial components of load due to bending of the specimen.

**Torsional Strength of Tubing.**—The analysis of test data on the torsion of 102 tubes of 17ST aluminum alloy has been completed and design charts have been computed from which the twisting moment at failure of tubes falling into the range of dimensions and of properties of those tested may be read off as a function of the wall thickness and the outside diameter of the tube as well as the yield point in tension and the ultimate strength in tension of the tube material.

The strength of the steel tubes could be represented as a nomogram involving three variables, while the strength of the 17ST aluminum alloy tubes could be shown as a single curve. The difference in behavior of the two sets of tubes may be ascribed to the much greater uniformity in properties of 17ST tubes as compared to the steel tubes.

Both design charts clearly showed the three types of failure that may be expected in tubes of the dimensions tested. Very thin tubes failed by elastic two-lobe buckling at twisting moments that scattered about the values predicted from Donnell's theory for the torsion of tubes with clamped ends (Technical Report No. 479); only 3 of the steel tubes and 12 of the 17ST tubes were sufficiently thin to fail in this manner. Most of the tubes (58 of the steel tubes and 72 of the 17ST tubes) had sufficiently thick walls to show some yielding before failure by buckling could occur; the stress at failure in this region of combined plastic failure and buckling was found to increase linearly with the ratio of wall thickness to diameter of the tube. The shear stress for the third type of failure is inde-

pendent of the wall thickness and appears to represent yielding of the material in pure shear. Two of the steel tubes and 20 of the 17ST tubes failed in this manner. The maximum length of the tubes, 60 inches, was not sufficient to indicate any lowering in strength with length due to helical deformation of the axis of the tube for tubes failing by plastic buckling or by plastic shear; in the cases of the tubes failing elastically the lowering in strength corresponds roughly to the predictions of Donnell's theory.

A report describing the results of tests on both chrome-molybdenum steel tubes and duralumin tubes is being prepared.

**Propeller Vibration.**—A paper outlining the method of determining stresses in nonrotating blades that was used at the National Bureau of Standards was published in the February 1935 issue of the Journal of Research of the National Bureau of Standards.

The theoretical method for determining the stress distribution in a nonrotating propeller blade vibrating with a natural frequency that is described in this paper was extended to rotating propellers in order to determine the change in stress distribution under the action of the centrifugal forces due to rotation.

Further development work has been done on a vibration indicator for measuring the amplitude of torsional vibration of the propeller shaft. Particular attention has been given to the design of an instrument that would be free from natural frequencies within the range of frequencies encountered. Such an instrument would give a meter reading proportional to the angular velocity and independent of the frequency.

A method has been developed for calibrating each instrument for frequencies ranging from 20 to 180 cycles per second.

**Airship Girders and Airship Structural Members.**—Tensile tests have been made on samples of Alclad sheet 0.01 inch thick cut from the hull of the metal-clad airship MC-2 after 6 years of service. These samples were chosen after thorough visual inspection as representative of the worst-corroded areas on the airship. None of these samples indicate any structurally significant deterioration of the underlying duralumin.

Metallographic examination showed that as in the previous samples the corrosion was in general slight, being confined to small isolated areas. In by far the greater number of these the corrosive attack had not penetrated through the aluminum protective layer.

In some few areas the attack has removed the greater part of the aluminum coating over areas a few tenths of an inch across, but in no case has there been any appreciable attack on the underlying duralumin.

Comparison with previous examinations indicates that the corrosion is proceeding by slow increase in

area of the spots already attacked rather than by the start of new centers of attack.

The condition of this thin sheet after 6 years of exposure is further evidence of the great efficacy of aluminum coatings in protecting structural aluminum alloys.

Further studies have been made of aluminum-alloy girders such as are used in the construction of airships. Column tests have been made in the large Emery testing machine on experimental girders approximately 132 inches long which had a ratio of length to radius of gyration of about 47.

**Flat Plates under Normal Pressure.**—Further attempts have been made to find a quantitative explanation of the straight-line relationship between center deflection and pressure at high pressures, which was a dominant feature of all the flat-plate tests made at the National Bureau of Standards.

It was hoped that a comparison of the test results for long plates with Boobnoff's relatively rigorous analysis for infinitely long plate strips under normal pressure would provide such an explanation. Actually it was found that the observed center deflections for the long plates showed a much larger scatter about the theoretical values than those for the square plates. The most plausible explanation of this behavior seemed to be a failure to realize the condition of rigid clamping at the edges assumed in the theory. In square plates this condition can be approached more easily than in long plates because they can be held more rigidly.

With the failure of the tests on long plates to provide an explanation it was decided to consider the case that comes closest to the long plate in simplicity, that is, circular plates with clamped edges. The theory for this type of plate has recently been developed in detail by Stewart Way. At the same time it is possible to realize the theoretical clamping conditions much more nearly than for long plates. A fixture for testing circular plates has accordingly been designed in which particular attention was given to the method of holding the edges in order to realize as closely as possible the theoretical boundary conditions of zero slope and zero deflection at the edge of the plate. This fixture has been nearly completed in the shop.

The work in the shop was paralleled by a careful check of Way's article for the purpose of deriving charts that would assist in interpreting the data to be obtained in the tests of circular plates yet to be made.

**Strength of Welded Joints in Tubular Members for Aircraft.**—The report of this investigation is practically completed and its publication is expected in the near future.

**Strength of Riveted Joints in Aluminum Alloy.**—Progress has been made in designing and constructing equipment for fabricating and testing riveted joints. Tests are now being made to determine the optimum conditions for driving aluminum-alloy rivets by the squeeze method. The driving load required to form a head of satisfactory strength without excessive deformation of the sheets is being determined for rivets having round, brazier, mushroom, and flat heads. Sufficient data have not yet been obtained to warrant specific conclusions.

#### SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

The research on stressed-skin or monocoque structures has been directed along fundamental lines, and an attempt has been made to carry the study of each case to such a point that the results could be used directly in analysis or design. Summaries of the literature on certain phases of the subject have been made, when possible, to aid the designer in his calculations of the strength and stiffness of the airplane structure, and a bibliography on monocoque construction for aircraft has been prepared. In addition, a number of university theses relating to monocoque design are reviewed each year for possible publication, and suggestions are made, on request, for research in other than governmental agencies.

**Design of Rings.**—The report on the stress analysis of rings, completed last year, has been revised according to the suggestions of the subcommittee and has been issued as Technical Report No. 509.

**Strength of Thin-Walled Cylinders of Circular Section.**—A report on the strength of 100 thin-walled cylinders of circular section in combined transverse shear and bending has been completed and published as Technical Note No. 523. In the report the results of the tests are summarized in the form of a chart giving the strength of a cylinder under combined transverse shear and bending in terms of the strength of the same cylinder in pure bending. In order to enter the chart it is necessary to know the loading condition described by the ratio

$$\frac{M}{rV} \quad \frac{\text{Moment}}{\text{Radius} \times \text{shear}}$$

the allowable stress on the extreme fiber in pure bending  $S_b$ , and the allowable shearing stress at the neutral axis in combined transverse shear and bending  $S_v$ . Experimentally, it was found that  $S_v = 1.25 S_s$ , where  $S_s$  is the allowable shearing stress in torsion. The chart clearly shows how the presence of shear reduces the bending strength of a cylinder and shows the importance of the ratio  $S_b/S_v$  in establishing the reduced strength.

**Strength of Thin-Walled Cylinders of Elliptic Section.**—Because monocoque fuselages are frequently oval in cross section, strength tests have been made on 120 thin-walled cylinders of elliptic section, the results of which are presented in Technical Note No. 527. In torsion it was found that the shearing stress at failure (maximum torque), calculated by the membrane analogy, was the same as for the circumscribed circular cylinder of the same length and sheet thickness. The calculated shearing stress, however, must be regarded as analogous to the modulus of rupture in beams because, when the maximum torque was developed, large wrinkles were present on the flat sides of the ellipse.

For pure bending in the plane of the major axis, the calculated stress on the extreme fiber at failure varied somewhat with the eccentricity of the ellipse, but the points were scattered so widely that the strength should be estimated after consideration of the test data. Design values may then be chosen more or less conservatively as desired.

In combined transverse shear and bending where the loads are applied in the plane of the major axis of the ellipse, it was found that the strength could be given by the same chart as for circular cylinders if the loading condition  $M/rV$  were replaced by a corresponding term  $M/r'V$  where  $r'$  varies with the eccentricity of the ellipse. For zero eccentricity, the formulas for  $r'$  reduce to  $r$ , the radius of a circular cylinder.

**Bending Stresses Due to Torsion in Cantilever Box Beams.**—A report on the bending stresses due to torsion in cantilever box beams has been prepared and issued as Technical Note No. 530. The problem considered is a rectangular box beam built in at one end. The restraint against warping at the built-in end causes bending stresses to be developed in the beam when torques are applied at the free end or at any inboard station. Formulas are given for calculating these bending stresses; they show that the bending stresses due to torsion are a maximum at the built-in end and reduce to very small values at a distance of one chord from the root. The specific cases to which the formulas apply are: (a) When the walls of the box are so thick that they do not buckle under shear; (b) when all the walls are so thin that they form diagonal-tension fields under shear; (c) when only the top and bottom walls, which correspond to the upper and lower surfaces of a wing, buckle to form diagonal-tension fields.

In order to check the formulas for the bending stresses due to torsion, tests were made on three box beams in which the differences consisted of changes in the thickness of the top and bottom sheet. For the beam with the thinnest sheet, diagonal-tension fields formed at low loads, and the agreement with the formulas was good, based upon measurements of stress

at the corners of the box near the built-in end. As the sheet thickness increased, however, the observed stresses were correspondingly less than the theoretical stresses. It was concluded that the failure to check the theoretical stresses for the beams with the thicker sheets was caused by the greater inefficiency of the bulkheads in maintaining the profile of the cross section.

**Torsional Stiffness of Shells with Interior Webs.**—As stiffness is a factor that is beginning to be specified in design, a report on the torsional stiffness of shells with interior webs has been issued as Technical Note No. 542. The problem is associated with metal wing design. From the results of tests made by the Army Air Corps on a series of duralumin and steel box beams of uniform section, it was found that the experimental stiffness averages about 0.9 of the theoretical. With this experimental factor, it was possible to check the measured torsional stiffness of two stressed-skin wings also tested by the Army Air Corps.

**Cross Method of Moment Distribution.**—Although the Cross method of moment distribution is not directly related to the monocoque problem, there are, nevertheless, problems in monocoque design to which the principles of moment distribution can be applied. A Stanford University thesis entitled "Principal Effects of Axial Load on Moment Distribution Analysis of Rigid Structures", by Benjamin Wylie James, which was referred to the subcommittee, has been reviewed and published as Technical Note No. 534.

As a result of the review of James' thesis, a second report is being prepared in which the question of convergence of the Cross method in the consideration of the effects of axial load is discussed. The question of convergence is closely related to the stability of compression members in trusses and stiffeners in stressed-skin structures, and the general subject is being studied in connection with column data obtained from the Ford Motor Company.

**Strength of Stiffeners.**—The study of the strength of stiffeners in stressed-skin structures from the column data obtained from the Ford Motor Company has continued during the past year. The progress made in separating the general problem into its component problems indicates that a report will be completed for publication this coming year. For each type of failure in the column or stiffener, there is a corresponding strength. The problem is also complicated by the fact that the practical factors of end conditions and eccentricities must be studied in regard to each type of failure and the various sectional shapes.

**Compressive Strength of Corrugated Sheet.**—With the cooperation of Prof. A. S. Niles, of Stanford University, a report summarizing the information on the compressive strength of corrugated sheet is being prepared for publication.

**Monocoque Cylinders and the Structure of Rigid Airships.**—A paper on the analogy between the monocoque cylinder and the structure of rigid airships was presented to the airship forum held at the Guggenheim Airship Institute at Akron, Ohio, on July 25 and 26, 1935. In both the cylinder and the airship the material is disposed in a thin region at the circumference of the cross section and the strength of the longitudinal elements depends on the supporting effect of the transverse elements.

The results of the extensive tests on thin-walled cylinders in torsion, compression, pure bending, and combined transverse shear and bending that have been made under the direction of the Subcommittee on Research Program on Monocoque Design were summarized and discussed in the paper in relation to the corresponding problems in the strength of rigid airships. It was shown how slight imperfections of workmanship and the finite strength of actual materials cause the strengths determined in tests to scatter widely at values considerably less than the values given by the classical theory of elasticity. The question was then raised: Is there a similar reduction in the strength of airship hulls and has it been allowed for in design? While it does not appear that any of the recent airships have had deficient strength in this respect, attention was called to the desirability of studying the stability of the hull structure of airships, particularly if the trend is toward larger airships with wider spacing of the main frames, more intermediate frames between adjacent main frames, and more longitudinals in the periphery of the section.

#### SUBCOMMITTEE ON METHODS AND DEVICES FOR TESTING AIRCRAFT MATERIALS AND STRUCTURES

During the past year this subcommittee has been preparing a report on strain gages, giving information concerning about 60 strain gages which are now being built by various manufacturers or which have been developed by research agencies, and summarizing in tabular form pertinent information regarding their use. Photographs and a brief description of each gage are being prepared, as well as a general discussion of the various types.

#### SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

During the past year a number of problems were considered by the Subcommittee on Miscellaneous Materials and Accessories for possible investigation at the National Bureau of Standards under the direction of the subcommittee. At a meeting of the subcommittee held on August 2, 1935, five such problems were discussed, and a report on this discussion was pre-

sented at a meeting of the Committee on Aircraft Structures and Materials on September 18, 1935. These five problems are briefly outlined below.

**Thermal and Acoustical Insulation for Airplanes.**—Commercial air lines have found from experience that passengers and operators appreciate the added comfort produced by insulation of their airplanes. The insulating material used in commercial airplanes is effective when first installed, and the same material can be used for both acoustical and thermal insulation. Such a material is characterized by a fibrous or cellular structure, the insulating value being largely dependent upon the enclosed or entrapped air. When the insulation is thoroughly cooled, as by flying for some time at high altitudes, and the airplane is then landed in a warm moist atmosphere, water condenses in the insulation, tending to fill the air spaces, thereby decreasing the insulating value and increasing the weight. Under certain conditions this effect may become cumulative.

Information is to be sought from airplane operators and manufacturers as to the relative importance of this problem. Further consideration must await the development of this information.

**Plastic Deformation of Rubber under Compression.**—The problem of the plastic deformation of rubber under compression was considered for investigation because of its practical importance and the inadequacy of present knowledge. Some of the questions to be determined in such an investigation are the change with time in the dimensions of a rubber part loaded in compression, the effect of change in temperature, and the effect of varying the composition of the rubber or of substituting a synthetic product such as thickol or duprene for the rubber.

After inquiry it was found that work on this project was being conducted by the Matériel Division of the Army Air Corps and by the industry.

**Artificial-Resin Gluer.**—Because of the great variations in raw materials, in methods of processing, and in formulation, it was proposed that a research be undertaken on artificial-resin adhesives suitable for wood in aircraft construction, including first a study of the properties of existing adhesives or others of this class as developed, and second a study of the technique of their use and application to aircraft members.

In view of the fact that wood is being superseded by metal in modern aircraft construction, it was decided that this problem need not be investigated at present.

**Methods for Testing and Evaluation of Paints and Similar Coatings.**—As the extreme vibration and great changes in temperature encountered by aircraft make the proper selection of paint and similar coatings for such structures unusually difficult, and as the rapid

development of synthetic materials for the vehicles in these coatings makes it difficult, if not impossible, to evaluate such products by composition, it was thought desirable that an investigation be undertaken to develop methods for the accelerated testing and evaluation of paints and similar coatings for aircraft.

Discussion of this problem indicated that, in the opinion of the members of the subcommittee, protective coatings at the present time were generally satisfactory for the prevention of corrosion.

Development of a Flexible Substitute for Glass.—The substitutes for glass now on the market for use in windshields and windows for aircraft are composed

of cellulose esters or of glyptal compounds or of urea formaldehyde condensation products. None of the materials at present in use, although they have many desirable features, are perfect. To be wholly satisfactory, the material, besides being transparent and flexible, must be hard enough to resist scratching, must not become plastic at high temperatures nor brittle at low temperatures, and must not become clouded, crazed, nor yellow on continued exposure to sunlight.

This problem has been approved for investigation on recommendation of the Subcommittee on Miscellaneous Materials and Accessories, and the work is now under way at the National Bureau of Standards.

## PART II

### ORGANIZATION AND GENERAL ACTIVITIES

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#### ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. Code, title 50, sec. 151). The Committee is composed of 15 members appointed by the President and serving as such without compensation. The law provides that the members shall include 2 representatives each from the War and Navy Departments and 1 each from the Smithsonian Institution, the Weather Bureau, and the National Bureau of Standards, together with not more than 8 additional persons "who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." One of these eight is a representative of the Bureau of Air Commerce of the Department of Commerce. Under the rules and regulations governing the work of the Committee as approved by the President, the Chairman and Vice Chairman of the Committee are elected annually.

During the past year there was one change in the membership of the main Committee. This was caused by the relief of Brigadier General Henry C. Pratt, Air Corps, United States Army, Chief of the Matériel Division, Wright Field, Dayton, Ohio, and his transfer to other duties. He was succeeded on this Committee by Brigadier General Augustine W. Robins, Air Corps, United States Army, the new Chief of the Matériel Division, whose commission was signed by President Roosevelt under date of March 23, 1935.

The executive offices of the Committee, including its offices of aeronautical intelligence and aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. It is the designated depository for scientific and technical data on aeronautics secured from all parts of the world. The material is classified, cataloged, and disseminated.

To assist in the collection of current scientific and technical information and data, the Committee maintains a technical assistant in Europe with headquarters at the American Embassy in Paris.

#### CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed \$75,000."

The work of considering aeronautical inventions and designs submitted is under the supervision of the Committee on Aeronautical Inventions and Designs.

#### ANALYSIS OF AIRCRAFT ACCIDENTS

A standard method for the analysis of aircraft accidents proposed by the Committee on Aircraft Accidents, approved by the National Advisory Committee, and published as Technical Report No. 357, has been followed for the past several years by the War, Navy, and Commerce Departments. During this period the practical value of the method, which provides for the classification of accidents according to their nature and their results and for their analysis according to both immediate and underlying causes, has been definitely proved. However, questions of interpretation of some of the definitions have arisen and instances have occurred for which the specified classifications seemed inadequate.

The Committee on Aircraft Accidents, which includes in its membership representatives of the air organizations of the War, Navy, and Commerce Departments, is therefore engaged in the revision of Report No. 357, incorporating modifications in the standard analysis method and providing clarification of a number of the definitions, to meet the difficulties which have arisen.

In connection with the classification of accidents according to the extent of injury to personnel, the com-

mittee plans to give consideration to the views and recommendations of medical representatives of the air organizations of the three departments. It is expected also that further consideration will be given to the correlation between the physiological and psychological characteristics of pilots and aircraft accidents.

#### AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

The National Advisory Committee for Aeronautics on March 16, 1935, appointed a Special Committee on Aeronautical Research in Educational Institutions for the purpose of preparing a report on the relationship of universities and schools of aeronautical science to the National Advisory Committee for Aeronautics. The special committee was organized as follows:

Hon. Willis Ray Gregg, Chairman (Chief United States Weather Bureau).

Col. Porter H. Adams, President Norwich University.

Commander Garland Fulton (C. C.), United States Navy.

Dr. George W. Lewis, National Advisory Committee for Aeronautics.

Dr. John L. Newcomb, President University of Virginia.

Brig. Gen. Henry C. Pratt, Air Corps, United States Army.

Hon. Edward P. Warner.

Dr. John B. Whitehead, Dean of Engineering Johns Hopkins University.

The special committee reviewed the history of the relations between the National Advisory Committee for Aeronautics and educational institutions with respect to the conduct of aeronautical research in such institutions. The members discussed generally and at length the recommendations of the Federal Aviation Commission on this subject and practical means of carrying them into effect. The recommendations of the special committee were as follows:

(1) That the present policy of the National Advisory Committee for Aeronautics with respect to cooperation with members of the faculties of universities in encouraging scientific investigations of aeronautical problems of a fundamental character be continued.

(2) That the National Advisory Committee for Aeronautics endeavor to secure the appropriation of additional funds for this special purpose, with an estimate of \$25,000 for the next fiscal year, 1936, for allocation in the discretion of the Committee.

(3) That, with the objective of producing useful research information, allotments be made from such special funds for financing particular scientific investigations approved by the National Advisory Committee for Aeronautics upon a showing of their probable usefulness and value to aeronautics; but that no allotments be made for the specific purpose of supporting aeronautical activities in universities.

The recommendations of the Special Committee on Aeronautical Research in Educational Institutions were approved by the National Advisory Committee for Aeronautics and an estimate of \$25,000 for this purpose was included in a supplemental appropriation

carried in the Second Deficiency Act approved August 12, 1935. This Committee is pleased to report that contracts for special reports requiring original research in aeronautics have been made with various educational institutions and that a start has thus been made in carrying into effect the recommendations of the Federal Aviation Commission on this subject.

#### COOPERATION WITH THE AIRCRAFT INDUSTRY

In the formulation of the Committee's program of research, provision is made for the inclusion of those problems that are of particular interest and importance to commercial aeronautics. The Committee keeps in continuous touch with the research needs of the aircraft industry, as the problems of the manufacturers are constantly being presented to the Committee in correspondence and through personal contacts and informal conferences, and advantage is taken of every opportunity to obtain the comments and suggestions of the industry in connection with the Committee's research programs.

It is expected that special opportunity for contact with the problems of the industry will be provided by the policy recently adopted by the Committee as a result of recommendation of the Federal Aviation Commission, whereby members of the industry are to be invited from time to time to attend meetings of the technical subcommittees of the Committee, for the purpose of discussing in detail the particular problems encountered by the industry which fall within the scope of the activities of these subcommittees.

Every effort is made to place in the hands of the industry as promptly as possible the results of researches which are of particular value to commercial aeronautics. When in the course of an investigation it appears that the results so far obtained will be of special interest and importance to the industry prior to the preparation of a formal report for publication, the Committee issues the data in advance form to American manufacturers and to the Government services for their confidential information. During the past year information in this form has been made available to American manufacturers on a basic investigation of wing-fuselage interference in the variable-density wind tunnel; on a large-scale boundary-layer investigation in the 20-foot wind tunnel; on the reduction of hinge moments of airplane control surfaces by tabs; on the characteristics of the N. A. C. A. 23012 airfoil; and on the investigation of a number of lateral control and high-lift devices.

**Annual Research Conference.**—Another means of keeping the Committee in touch with the needs of the industry is the annual aircraft engineering research conference held at the Committee's laboratories each May. The purpose of this conference, which was first



held in 1926, is to enable representatives of the industry to obtain first-hand information on the Committee's research facilities and the results obtained in its investigations, and to afford them an opportunity to present to the Committee their suggestions for investigations to be included in the Committee's research program.

The Tenth Annual Aircraft Engineering Research Conference was held on May 22, 1935, at the Committee's laboratory at Langley Field, and was presided over by Dr. Joseph S. Ames, Chairman of the Committee. At this conference the Committee was represented by its officers, members of the main Committee, and members of the Committees on Aerodynamics and Power Plants for Aircraft.

At the morning session the principal investigations under way at the laboratory, both in aerodynamics and power plants, were explained by the engineers in charge of the work, and charts were exhibited showing some of the results obtained. The representatives of the industry were then conducted on a tour of inspection of the laboratory, and the research equipment was shown in operation.

In the afternoon 5 simultaneous conferences were held for the discussion of 5 different subjects, namely, high-lift devices and lateral control, flutter and vibration, cowlings and cooling of air-cooled engines, interference and aerodynamic efficiency, and compression-ignition engines. In addition, three small informal conferences were held on seaplanes, spinning, and rotating-wing aircraft. At these conferences the results of the Committee's researches were presented in further detail, and suggestions were submitted by the representatives of the industry for problems to be added to the Committee's program. These suggestions were referred to the Committee on Aerodynamics and the Committee on Power Plants for Aircraft and were considered by them in their preparation of the Committee's research program.

#### SUBCOMMITTEES

The Advisory Committee has organized a number of standing committees, with subcommittees, for the purpose of supervising its work in their respective fields. After a careful survey of its committees and subcommittees and their membership, the Advisory Committee, at its semiannual meeting on April 18, 1935, authorized a reorganization, in order to meet more effectively the present needs of aeronautical research. In this reorganization, which was effected during May, the Committee on Problems of Air Navigation and its Subcommittee on Instruments were discharged, in view of the overlapping of their functions with the functions of the Bureau of Air Commerce, and the Subcommittee on Meteorological Problems, which had been a subcommittee of the Committee on Problems of Air

Navigation, was transferred to the Committee on Aerodynamics. Two new subcommittees were established—a Subcommittee on Seaplanes, under the Committee on Aerodynamics, and a Subcommittee on Aircraft Fuels and Lubricants, under the Committee on Power Plants for Aircraft. The name of the Committee on Materials for Aircraft was changed to Committee on Aircraft Structures and Materials, and the names of three of its subcommittees were changed.

The three main technical Committees on Aerodynamics, Power Plants for Aircraft, and Aircraft Structures and Materials and their subcommittees supervise and direct the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies. Their work has been described in part I.

The organization of the committees and subcommittees is as follows:

#### COMMITTEE ON AERODYNAMICS

Hon. Edward P. Warner, Chairman.

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.

Dr. L. J. Briggs, National Bureau of Standards.

Theophile dePort, Matériel Division, Army Air Corps, Wright Field.

Lt. Comdr. W. S. Diehl (C. C.), United States Navy.

Dr. H. L. Dryden, National Bureau of Standards.

Lt. Col. O. P. Echols, Air Corps, United States Army, Matériel Division, Wright Field.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Hon. Willis Ray Gregg, Weather Bureau.

Lawrence V. Kerber, Bureau of Air Commerce, Department of Commerce.

Lt. Comdr. R. D. MacCart (C. C.), United States Navy.

Elton W. Miller, National Advisory Committee for Aeronautics.

Lt. Comdr. Donald Royce (C. C.), United States Navy.

Dr. David W. Taylor.

Maj. J. G. Taylor, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

#### SUBCOMMITTEE ON AIRSHIPS

Hon. Edward P. Warner, Chairman.

Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.

Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.

Capt. Howard H. Couch, Air Corps, United States Army, Matériel Division, Wright Field.

Commander Garland Fulton (C. C.), United States Navy.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Ralph H. Upson, Ann Arbor, Mich.

#### SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Hon. Willis Ray Gregg, Weather Bureau, Chairman.

Dr. W. J. Humphreys, Weather Bureau.

Dr. J. C. Hunsaker, Massachusetts Institute of Technology.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Delbert M. Little, Weather Bureau.

Dr. Charles F. Marvin.

Lt. Comdr. F. W. Reichelderfer, United States Navy, Naval Air Station, Lakehurst.

Dr. C. G. Rossby, Massachusetts Institute of Technology.

Eugene Sibley, Bureau of Air Commerce, Department of Commerce.

Capt. Alfred H. Thiessen, United States Army, Signal Corps, War Department.

#### SUBCOMMITTEE ON SEAPLANES

Capt. H. C. Richardson (C. C.), United States Navy, Chairman.

Theophile dePort, Matériel Division, Army Air Corps, Wright Field.

Lt. Comdr. W. S. Diehl (C. C.), United States Navy.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

J. T. Gray, Bureau of Air Commerce, Department of Commerce.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Lt. Comdr. K. McGinnis, United States Navy.

Maj. J. G. Taylor, Air Corps, United States Army, Matériel Division, Wright Field.

Starr Truscott, National Advisory Committee for Aeronautics.

#### COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Hon. William P. MacCracken, Jr., Chairman.

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.

Dr. H. C. Dickinson, National Bureau of Standards.

John H. Geisse, Bureau of Air Commerce, Department of Commerce.

Capt. James M. Gillespie, Air Corps, United States Army, Matériel Division, Wright Field.

Carlton Kemper, National Advisory Committee for Aeronautics.

Lt. Comdr. T. C. Lonnquest, United States Navy.

G. W. Newton, Bureau of Air Commerce, Department of Commerce.

Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

#### SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Dr. H. C. Dickinson, National Bureau of Standards, Chairman.

Dr. O. C. Bridgeman, National Bureau of Standards.

Lt. C. F. Coe, United States Navy.

H. K. Cummings, National Bureau of Standards.

Capt. James M. Gillespie, Air Corps, United States Army, Matériel Division, Wright Field.

L. S. Hobbs, The Pratt & Whitney Aircraft Company.

Lt. F. D. Klein, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Lt. Comdr. T. C. Lonnquest, United States Navy.

G. W. Newton, Bureau of Air Commerce, Department of Commerce.

Arthur Nutt, Wright Aeronautical Corporation.

Addison M. Rothrock, National Advisory Committee for Aeronautics.

#### COMMITTEE ON AIRCRAFT STRUCTURES AND MATERIALS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.  
Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.

Capt. Howard Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

S. K. Colby, Aluminum Co. of America.

Lt. N. A. Drait (C. C.), United States Navy.

Warren E. Emley, National Bureau of Standards.

Commander Garland Fulton (C. C.), United States Navy.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

J. T. Gray, Bureau of Air Commerce, Department of Commerce.

C. H. Helms, National Advisory Committee for Aeronautics.

Dr. Zay Jeffries, American Magnesium Corporation.

J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

H. S. Rawdon, National Bureau of Standards.

E. C. Smith, Republic Steel Corporation.

Starr Truscott, National Advisory Committee for Aeronautics.

Hon. Edward P. Warner.

#### SUBCOMMITTEE ON METALS USED IN AIRCRAFT

H. S. Rawdon, National Bureau of Standards, Chairman.

J. P. Bailey, Bureau of Air Commerce, Department of Commerce.

Commander Garland Fulton (C. C.), United States Navy.

Dr. Zay Jeffries, American Magnesium Corporation.

J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

E. C. Smith, Republic Steel Corporation.

Prof. H. L. Whittemore, National Bureau of Standards.

#### SUBCOMMITTEE ON STRUCTURAL LOADS AND METHODS OF STRUCTURAL ANALYSIS

Starr Truscott, National Advisory Committee for Aeronautics, Chairman.

Capt. Howard Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

M. P. Crews, Bureau of Air Commerce, Department of Commerce.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Capt. C. F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Lt. Comdr. R. D. MacCart (C. C.), United States Navy.

Prof. J. S. Newell, Massachusetts Institute of Technology.

Lt. Comdr. H. R. Oster (C. C.), United States Navy, Naval Aircraft Factory.

Henry J. E. Reid, National Advisory Committee for Aeronautics.

Richard V. Rhode, National Advisory Committee for Aeronautics.

Dr. L. B. Tuckerman, National Bureau of Standards.

## SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Chairman.

Capt. Howard Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Capt. C. F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.

Eugene E. Lundquist, National Advisory Committee for Aeronautics.

Lt. Comdr. R. D. MacCart (C. C.), United States Navy.

F. R. Shanley, Bureau of Air Commerce, Department of Commerce.

Dr. L. B. Tuckerman, National Bureau of Standards.

## SUBCOMMITTEE ON METHODS AND DEVICES FOR TESTING AIRCRAFT MATERIALS AND STRUCTURES

Henry J. E. Reld, National Advisory Committee for Aeronautics, Chairman.

J. P. Bailey, Bureau of Air Commerce, Department of Commerce.

Capt. Howard Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Eugene E. Lundquist, National Advisory Committee for Aeronautics.

Lt. Comdr. Karl Schmidt (C. C.), United States Navy, Naval Aircraft Factory.

R. L. Templin, Aluminum Co. of America.

George W. Trayer, Forest Products Laboratory.

Dr. L. B. Tuckerman, National Bureau of Standards.

## SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

Warren E. Emley, National Bureau of Standards, Chairman.

C. J. Cleary, Matériel Division, Army Air Corps, Wright Field.

John Easton, Bureau of Air Commerce, Department of Commerce.

C. H. Helms, National Advisory Committee for Aeronautics.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

J. E. Sullivan, Bureau of Aeronautics, Navy Department.

G. W. Trayer, Forest Products Laboratory.

P. H. Walker, National Bureau of Standards.

## COMMITTEE ON AIRCRAFT ACCIDENTS

Hon. Edward P. Warner, Chairman.

Lt. (j. g.) S. B. Dunlap, United States Navy.

Capt. E. V. Harbeck, Jr., Air Corps, United States Army.

J. W. Lankford, Bureau of Air Commerce, Department of Commerce.

Dr. George W. Lewis, National Advisory Committee for Aeronautics.

Lt. Comdr. A. O. Rule, United States Navy.

Joe T. Shumate, Bureau of Air Commerce, Department of Commerce.

Capt. Lowell H. Smith, Air Corps, United States Army.

## COMMITTEE ON AERONAUTICAL INVENTIONS AND DESIGNS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.

Hon. Willis Ray Gregg, Weather Bureau.

Brig. Gen. A. W. Robins, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. David W. Taylor.

Commander R. D. Weyerbacher (C. C.), United States Navy.

John F. Victory, Secretary.

## COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

Dr. Joseph S. Ames, Chairman.

Hon. Willis Ray Gregg, Weather Bureau, Vice Chairman.

Miss M. M. Muller, Secretary.

## COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, Chairman.

Dr. David W. Taylor, Vice Chairman.

John F. Victory, Secretary.

## TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft.

The Committee issued during the past year a bibliography of aeronautics for the year 1931. It had previously issued bibliographies for the years since 1909. The bibliography for 1932 is now in the hands of the printer and should be ready for distribution during the coming year. All issues of the Bibliography of Aeronautics to date were prepared by Paul Brockett.

The following are lists of the publications issued:

## LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

- | No.  |  |
|------|--|
| 508. | Analysis of 2-Spar Cantilever Wings with Special Reference to Torsion and Load Transference. By Paul Kuhn, N. A. C. A.   |
| 509. | General Equations for the Stress Analysis of Rings. By Eugene E. Lundquist and Walter F. Burke, N. A. C. A.  |
| 510. | Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. XIII—Auxiliary Airfoils Used as External Ailerons. By Fred E. Weick and Richard W. Noyes, N. A. C. A. |

511. The Effect of Baffles on the Temperature Distribution and Heat-Transfer Coefficients of Finned Cylinders. By Oscar W. Schey and Vern G. Rollin, N. A. C. A.
512. Some Factors Affecting Combustion in an Internal-Combustion Engine. By A. M. Rothrock and Mildred Cohn, N. A. C. A.
513. Experimental Investigation of the Robinson-Type Cup Anemometer. By M. J. Brevoort and U. T. Joyner, N. A. C. A.
514. The Measurement of the Field of View from Airplane Cockpits. By Melvin N. Gough, N. A. C. A.
515. Full-Scale Wind-Tunnel Tests of a PCA-2 Autogiro Rotor. By John B. Wheatley and Manley J. Hood, N. A. C. A.
516. Potential Flow about Elongated Bodies of Revolution. By Carl Kaplan, N. A. C. A.
517. Flight Investigation of Lateral Control Devices for Use with Full-Span Flaps. By H. A. Soulé and W. H. McAvoy, N. A. C. A.
518. The Drag of Airplane Wheels, Wheel Fairings, and Landing Gears. II—Nonretractable and Partly Retractable Landing Gears. By David Biermann and William H. Herrstein, Jr., N. A. C. A.
519. Spinning Characteristics of Wings. I—Rectangular Clark Y Monoplane Wing. By M. J. Bamber and C. H. Zimmerman, N. A. C. A.
520. A Comparison of Fuel Sprays from Several Types of Injection Nozzles. By Dana W. Lee, N. A. C. A.
521. An Analysis of Longitudinal Stability in Power-Off Flight with Charts for Use in Design. By Charles H. Zimmerman, N. A. C. A.
522. The Drag of Airplane Wheels, Wheel Fairings, and Landing Gears—III. By William H. Herrstein, Jr., and David Biermann, N. A. C. A.
523. The Influence of Wing Setting on the Wing Load and Rotor Speed of a PCA-2 Autogiro as Determined in Flight. By John B. Wheatley, N. A. C. A.
524. A Turbulence Indicator Utilizing the Diffusion of Heat. By G. B. Schubauer, National Bureau of Standards.
525. Some Effects of Injection Advance Angle, Engine-Jacket Temperature, and Speed on Combustion in a Compression-Ignition Engine. By A. M. Rothrock and C. D. Waldron, N. A. C. A.
526. Noise from Two-Blade Propellers. By E. Z. Stowell and A. F. Deming, N. A. C. A.
527. Air Flow in a Separating Laminar Boundary Layer. By G. B. Schubauer, National Bureau of Standards.
528. Reduction of Hinge Moments of Airplane Control Surfaces by Tabs. By Thomas A. Harris, N. A. C. A.
529. A Flight Investigation of the Spinning of the F4B-2 Biplane with Various Loads and Tail Surfaces. By N. F. Scudder and Oscar Seidman, N. A. C. A.
530. Characteristics of the N. A. C. A. 23012 Airfoil from Tests in the Full-Scale and Variable-Density Tunnels. By Eastman N. Jacobs and William C. Clay.
531. The Effect of Water Vapor on Flame Velocity in Equivalent CO-O<sub>2</sub> Mixtures. By Ernest F. Flock and H. Kendall King, National Bureau of Standards.
532. The Soap-Bubble Method of Studying the Combustion of Mixtures of CO and O<sub>2</sub>. By Ernest F. Flock and Carl H. Roeder, National Bureau of Standards.
533. Distribution and Regularity of Injection from a Multi-cylinder Fuel-Injection Pump. By A. M. Rothrock and E. T. Marsh, N. A. C. A.
534. Aerodynamic Characteristics of a Wing with Fowler Flaps, Including Flap Loads, Downwash, and Calculated Effect on Take-Off. By Robert C. Platt, N. A. C. A.
535. Hydrogen as an Auxiliary Fuel in Compression-Ignition Engines. By Harold C. Gerrish and Hampton H. Foster, N. A. C. A.
536. Wind-Tunnel Tests of a 10-Foot-Diameter Gyroplane Rotor. By John B. Wheatley and Carlton Bioletti, N. A. C. A.
537. Tests in the Variable-Density Wind Tunnel of Related Airfoils Having the Maximum Camber Unusually Far Forward. By Eastman N. Jacobs and Robert M. Pinkerton, N. A. C. A.
538. Altitude-Pressure Tables Based on the United States Standard Atmosphere. By W. G. Brombacher, National Bureau of Standards.
539. Investigation of Full-Scale Split Trailing-Edge Wing Flaps with Various Chords and Hinge Locations. By Rudolf Wallace, N. A. C. A.
540. Interference of Wing and Fuselage from Tests of 200 Combinations in the N. A. C. A. Variable-Density Tunnel. By Eastman N. Jacobs and Kenneth E. Ward, N. A. C. A.
541. Aerodynamic Characteristics of Wings with Cambered External-Airfoil Flaps, Including Lateral Control with a Full-Span Flap. By Robert C. Platt, N. A. C. A.

#### LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

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|------|--|
| No.  |  |
| 505. | The Effects of Full-Span and Partial-Span Split Flaps on the Aerodynamic Characteristics of a Tapered Wing. By Carl J. Wenzinger, N. A. C. A.                      |
| 506. | Experimental Verification of Theodorsen's Theoretical Jet-Boundary Correction Factors. By George Van Schlietett, Georgia School of Technology.                     |
| 507. | The Effects of Equal-Pressure Fixed Slots on the Characteristics of a Clark Y Airfoil. By Albert Sherman and Thomas A. Harris, N. A. C. A.                         |
| 508. | Landing Characteristics of an Autogiro. By William O. Peck, N. A. C. A.  |
| 509. | Tank Tests of Flat and V-Bottom Planing Surfaces. By James M. Shoemaker, N. A. C. A.   |
| 510. | The Calculated Effect of Trailing-Edge Flaps on the Take-Off of Flying Boats. By J. B. Parkinson and J. W. Bell, N. A. C. A.                                       |
| 511. | A Study of the Pitching Moments and the Stability Characteristics of Monoplanes. By George J. Higgins, University of Michigan.                                     |
| 512. | A Complete Tank Test of the Hull of the Sikorsky S-40 Flying Boat—American Clipper Class. By John R. Dawson, N. A. C. A.   |
| 513. | The Wave Suppressors Used in the N. A. C. A. Tank. By Starr Truscott, N. A. C. A.  |
| 514. | Effect of Combustion-Chamber Shape on the Performance of a Prechamber Compression-Ignition Engine. By C. S. Moore and J. H. Collins, Jr., N. A. C. A.              |
| 515. | Aerodynamic Effects of a Split Flap on the Spinning Characteristics of a Monoplane Model. By M. J. Bamber, N. A. C. A.   |
| 516. | Propeller Vibrations and the Effect of the Centrifugal Force. By T. Theodorsen, N. A. C. A.  |
| 517. | The Aerodynamic Forces and Moments on a Spinning Model of the F4B-2 Airplane as Measured by the Spinning Balance. By M. J. Bamber and C. H. Zimmerman, N. A. C. A. |
| 518. | Performance Tests of a Single-Cylinder Compression-Ignition Engine with a Displacer Piston. By C. S. Moore and H. H. Foster, N. A. C. A.                           |

510. Vortex Noise from Rotating Cylindrical Rods. By E. Z. Stowell and A. F. Deming, N. A. C. A.
520. Calculations of the Effect of Wing Twist on the Air Forces Acting on a Monoplane Wing. By G. Dütwyler, California Institute of Technology.
521. Full-Scale Force and Pressure-Distribution Tests on a Tapered U. S. A. 45 Airfoil. By John F. Parsons, N. A. C. A.
522. Tank Tests of a Model of a Flying-Boat Hull with a Fluted Bottom. By John R. Dawson, N. A. C. A.
523. Strength Tests of Thin-Walled Duralumin Cylinders in Combined Transverse Shear and Bending. By Eugene E. Lundquist, N. A. C. A.
524. Wind-Tunnel Tests of a Wing with a Trailing-Edge Auxiliary Airfoil Used as a Flap. By Richard W. Noyed, N. A. C. A.
525. The Aerodynamic Drag of Flying-Boat Hull Models as Measured in the N. A. C. A. 20-Foot Wind Tunnel—I. By Edwin P. Hartman, N. A. C. A.
526. Spinning Characteristics of Wings. Part II—Rectangular Clark Y Biplane Cellule: 25 Percent Stagger; 0° Decalage; Gap/Chord 1.0. By M. J. Bamber, N. A. C. A.
527. Strength Tests of Thin-Walled Duralumin Cylinders of Elliptic Section. By Eugene E. Lundquist and Walter F. Burke, N. A. C. A.
528. Wind-Tunnel Tests of a Cyclogiro Rotor. By John B. Wheatley and Ray Windler, N. A. C. A.
529. Analysis of a Strut with a Single Elastic Support in the Span, with Applications to the Design of Airplane Jury-Strut Systems. Part I—Derivation of Formulas, By A. Murray Schwartz, Stanford University. Part II—Experimental Investigation of Formulas. By Reid Bogert, Stanford University.
530. Bending Stresses Due to Torsion in Cantilever Box Beams. By Paul Kuhn, N. A. C. A.
531. Tank Tests of Model 11-G Flying-Boat Hull. By J. B. Parkinson, N. A. C. A.
532. Method of Testing Oxygen Regulators. By Harcourt Sonntag and E. L. Borlik, National Bureau of Standards.
533. The Thermodynamics of Combustion in the Otto Cycle Engine. By E. S. Taylor, Massachusetts Institute of Technology.
534. Principal Effects of Axial Load on Moment-Distribution Analysis of Rigid Structures. By Benjamin Wyllie James, Stanford University.
535. The Effect of Depth of Step on the Water Performance of a Flying-Boat Hull Model—N. A. C. A. Model 11-O. By Joe W. Bell, N. A. C. A.
536. The 6-Foot-4-Inch Wind Tunnel at the Washington Navy Yard. By G. L. Desmond and J. A. McCrary, Aerodynamical Laboratory, Navy Yard, Washington, D. C.
537. A Preliminary Determination of Normal Accelerations on Racing Airplanes. By N. F. Scudder and H. W. Kirschbaum, N. A. C. A.
538. A General Tank Test of N. A. C. A. Model 11-C Flying-Boat Hull, Including the Effect of Changing the Plan Form of the Step. By John R. Dawson, N. A. C. A.
539. Aerodynamic Characteristics of Several Airfoils of Low Aspect Ratio. By C. H. Zimmerman, N. A. C. A.
540. A Deflection Formula for Single-Span Beams of Constant Section Subjected to Combined Axial and Transverse Loads. By Walter F. Burke, N. A. C. A.
541. The Effect of the Angle of Afterbody Keel on the Water Performance of a Flying-Boat Hull Model. By John M. Allison, N. A. C. A.
542. The Initial Torsional Stiffness of Shells with Interior Webs. By Paul Kuhn, N. A. C. A.

## LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

- No.
755. Safety and Design in Airplane Construction. By Alfred Teichmann. From *Automobiltechnische Zeitschrift*, January 25, 1934.
756. The Behavior Under Shearing Stress of Duralumin Strip with Round, Flanged Holes. By Karl Schüssler. From *Luftfahrtforschung*, August 18, 1934.
757. The Aachen Wind-Tunnel Balance. By C. Wieselsberger. From *Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochschule Aachen*, No. 14, 1934.
758. The Processes in Spring-Loaded Injection Valves of Solid Injection Oil Engines. By O. Lutz. From *Ingenieur-Archiv*, vol. IV, no. 2, 1933.
759. The Effect of Weight and Drag on the Sinking Speed and Lift/Drag Ratio of Gliders. By R. Kosin. From *Luftfahrtforschung*, October 25, 1934.
760. Technical Aspects of the 1934 International Touring Competition (Rundflug). By R. Schulz and W. Pleines. From *Luftwissen*, September 15, and October 15, 1934.
761. Gliding in Convection Currents. By W. Georgii. From *Luftfahrtforschung*, October 25, 1934.
762. Effect of Aerodynamic Design on Glider Performance. By A. Lippisch. From *Luftfahrtforschung*, October 25, 1934.
763. The Heat Transfer of Cooling Fins on Moving Air. By Hans Doetsch. From *Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochschule Aachen*, no. 14, 1934.
764. The Aerodynamic Aspect of Wing-Fuselage Fillets. By H. Muttray. From *Luftfahrtforschung*, October 25, 1934.
765. The 1934 Contest for the Deutsch de la Meurthe Trophy. By Pierre Légière. From *L'Aéronautique*, July 1934; and *Aircraft Engineering*, July 1934.
766. The Aeronautical Laboratory of the Stockholm Technical Institute. By Ivar Malmer. From *Teknisk Tidskrift*, 1933.
767. Modification of Wing-Section Shape to Assure a Predetermined Change in Pressure Distribution. By A. Betz. From *Luftfahrtforschung*, December 5, 1934.
768. The Interdependence of Profile Drag and Lift with Joukowski Type and Related Airfoils. By H. Muttray. From *Luftfahrtforschung*, December 5, 1934.
769. The Bending of Beams with Thin Tension Flanges. By Placido Cicala. From *Atti della Reale Accademia delle Scienze di Torino*, vol. 69, 1933-34.
770. Hydrodynamic Tests of Models of Seaplane Floats. By Antonio Eula. From *L'Aerotecnica*, August-September 1934.
771. Ground Effect on the Take-Off and Landing of Airplanes. By Maurice Le Sueur. From *La Science Aérienne*, January-February 1934.
772. The Denis-Gruson Six-Component Wind-Tunnel Balance. Data received from Paris Office, N. A. C. A.
773. Experiments with Suction-Type Wings. By O. Schrenk. From *Luftfahrtforschung*, March 28, 1935.
774. Tension Fields in Originally Curved, Thin Sheets During Shearing Stresses. By H. Wagner and W. Ballerstedt. From *Luftfahrtforschung*, May 16, 1935.
775. Total-Head Meter with Small Sensitivity to Yaw. By G. Kiel. From *Luftfahrtforschung*, May 16, 1935.
776. A Discussion of the Several Types of Two-Stroke-Cycle Engines. By Herbert J. Venediger. From *Automobiltechnische Zeitschrift*, October 10 and October 25, 1934.

## LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

- No.
197. The De Havilland "Comet" Long-Range Airplane (British). A Low-Wing Cantilever Monoplane. From Flight, September 20, 1934.
198. Kay 331 Gyroplane (British). All-Metal Single-Seat Light Rotor Plane. From The Aeroplane, December 26, 1934.
199. Boulton Paul P. 71A Commercial Airplane (British). A Two-Engine Biplane. From Flight, January 31, 1935.

## FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1935, as contained in the Independent Offices Appropriation Act approved March 28, 1934, was \$707,792. This amount was increased by \$40,038 to provide for restoration of salaries of employees to a 100 percent basis. The total available for expenditure by this Committee for the fiscal year 1935 was therefore \$747,830. Of this amount a total of \$747,827 was expended as follows:

Personal services .....	\$616, 208
Supplies and materials.....	34, 190
Communication service.....	2, 051
Travel expenses.....	12, 311
Transportation of things.....	3, 612
Furnishing of electricity.....	28, 822
Repairs and alterations.....	3, 471
Special investigations and reports.....	16, 710
Equipment .....	30, 443
Expenditures .....	747, 827
Unobligated balance .....	3
Total, general appropriation.....	747, 830

The appropriation for printing and binding for 1935 was \$18,700, of which \$18,697 was expended.

No deposit has been made by this Committee to the credit of miscellaneous receipts during the fiscal year 1935. The sum of \$300 was received by this Committee as a special deposit to cover the cost of scientific services to be furnished private parties, but the investigations desired were not completed by June 30, 1935.

The appropriations for the current fiscal year 1936 are \$1,158,850 for general expenses and \$18,700 for printing and binding. This includes regular appropriations of \$839,500 contained in the Independent Offices Appropriation Act approved February 2, 1935, and a supplemental appropriation of \$338,050 contained in the Second Deficiency Act approved August 12, 1935.

From an allotment of \$478,300 from the Public Works Administration for the construction of a 500-mile-per-hour wind tunnel at Langley Field, the amount expended and obligated during the fiscal year 1935 was \$469,558.80.

Of the allotment of \$3,000 for participation by this Committee in the California Pacific International Exposition which opened at San Diego May 27, 1935, the amount expended and obligated as at June 30, 1935, was \$954.26.

The amount of \$6,600 was allotted to this Committee by the Department of Commerce, Bureau of Air Commerce, during the fiscal year 1935 for work to be performed in connection with the furtherance of the improvement of safety and efficiency in civil aviation, and of this amount \$6,213.38 was expended.

## CONCLUSION

This Committee wishes to express to the President and to the Congress its appreciation of the liberal support uniformly accorded its work in the fields of pure and applied research in aeronautics. It is grateful for the part it has thus been enabled to play, since its establishment in 1915, in the development of American aviation.

This Committee is convinced that its present status as an independent Government establishment has been largely responsible for its success. Were it not, however, for the full appreciation of the value of research and the effective support and cooperation of the Army Air Corps, the Navy Bureau of Aeronautics, and the Bureau of Air Commerce, the contributions of this Committee to the progress of American aeronautics would not have been possible.

This Committee is convinced that the continued coordination of the research needs of all branches of aviation in a comprehensive research program, with additional and enlarged research facilities available to the Committee for the prosecution of fundamental investigations, and with the continued confidence and cooperation of the governmental agencies concerned, as well as of the aircraft industry, there will continue to be gratifying progress in improving the performance, range, efficiency, and safety of American aircraft for the national defense, for commercial air transportation, and for private flying.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE  
FOR AERONAUTICS,  
JOSEPH S. AMES, *Chairman*.